U. S. DEPARTMENT OF AGRICULTURE,

BUREAU OF PLANT INDUSTRY,

B. T. GALLOWAY, *Chief of Bureau.*

# BULLETINS

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# BUREAU OF PLANT INDUSTRY.

## NOS. 255 TO 259.

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BUREAU OF PLANT INDUSTRY.

*Chief of Bureau*, BEVERLY T. GALLOWAY.
*Assistant Chief of Bureau*, WILLIAM A. TAYLOR.
*Editor*, J. E. ROCKWELL.
*Chief Clerk*, JAMES E. JONES.

# TITLES OF BULLETINS NOS. 255 TO 259 OF THE BUREAU OF PLANT INDUSTRY.

**Issued from June 29, 1912, to January 13, 1913.[1]**

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BULLETIN No. 255.—The Structure and Development of Crown Gall: A Plant Cancer. By Erwin F. Smith, Nellie A. Brown, and Lucia McCulloch. Issued June 29, 1912.

BULLETIN No. 256.—Heredity and Cotton Breeding. By O. F. Cook. Issued January 13, 1913.

BULLETIN No. 257—The Weed Factor in the Cultivation of Corn. By J. S. Cates and H. R. Cox. Issued October 15, 1912.

BULLETIN No. 258.—Some New Alfalfa Varieties for Pastures. By George W. Oliver. Issued January 13, 1913.

BULLETIN No. 259.—What Is Farm Management? By W. J. Spillman. Issued October 2, 1912.

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[1] Bulletins Nos. 244 to 249, 251 to 253, 260 to 268, 271, and 272 of the Bureau of Plant Industry were also issued during this period.



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U. S. DEPARTMENT OF AGRICULTURE.

**BUREAU OF PLANT INDUSTRY—BULLETIN NO. 255.**

B. T. GALLOWAY, *Chief of Bureau.*

# THE STRUCTURE AND DEVELOPMENT OF CROWN GALL:

## A PLANT CANCER.

BY

ERWIN F. SMITH,

*Pathologist in Charge of Laboratory of Plant Pathology,*

AND

NELLIE A. BROWN AND LUCIA McCULLOCH,

*Scientific Assistants.*

ISSUED JUNE 29, 1912.

WASHINGTON:

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## BUREAU OF PLANT INDUSTRY.

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# LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Plant Industry,
Office of the Chief,
*Washington, D. C., May 9, 1912.*

Sir: I have the honor to transmit herewith and to recommend for publication as Bulletin No. 255 of the special series of this bureau the accompanying technical paper by Dr. Erwin F. Smith, Miss Nellie A. Brown, and Miss Lucia McCulloch, entitled "The Structure and Development of Crown Gall: A Plant Cancer."

This paper is the result of many months of critical study of hundreds of serial sections prepared on the microtome; and so far as relates to the photographic demonstration of the presence of the causal organism within the proliferating cells, to several years of laborious and discouraging experimentation with a variety of fixing agents and stains. Only recently has it been possible to demonstrate clearly by means of the microscope the presence of the parasitic organism within the cells, although the authors have known for more than five years that this organism *must be* located within the cells, because in galls shown by the agar poured-plate method to contain the bacteria, no granules of any sort occur between the cells or in the lumen of the vessels.

Had Dr. Smith's researches on crown gall been confined only to morphology (excluding parasitology) it would be reasonable for him to make precisely the same statement now commonly made by research workers in cancer, viz, "The cell itself is the only parasite. That fully explains all the observed phenomena." But, adding the bacteriological evidence, we see for the first time clearly that while it is the rapidly proliferating cancer cells that do the mischief they are impelled to behave in this way only because they are under the stimulus of a foreign organism which does not destroy them, but irritates them to rapid division and passes over into certain of the daughter cells to repeat the process indefinitely. This, it can not be denied, is a discovery of the first magnitude in pathology.

A preliminary announcement of certain of these new discoveries was made a year ago, to wit, the existence of a tumor strand and of stem structure in secondary tumors. The paper herewith submitted

furnishes the promised photomicrographic proofs in support of those statements.

The interest which the preliminary statements have awakened, not only among plant pathologists, but also among medical men in all parts of the world, and the manifestly important bearing of these researches on the origin of malignant human and animal tumors, make it desirable to publish the investigations in full. It is recommended, therefore, that the paper be published as submitted, with all of its illustrations, and at as early a date as possible. The illustrations submitted are the essential part of the paper, the text, for the most part, being only a running commentary.

Respectfully,

B. T. GALLOWAY, *Chief of Bureau.*

Hon. JAMES WILSON,
*Secretary of Agriculture.*

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# THE STRUCTURE AND DEVELOPMENT OF CROWN GALL: A PLANT CANCER.

## INTRODUCTION.

This is a bulletin on the histology of crown gall. For five years the senior writer has been hammering away at the idea that crown gall of plants resembles malignant human tumors and can be made to throw a flood of light on the origin of the latter, which is still shrouded in obscurity and believed by the majority of pathologists to be of nonparasitic origin (vide Bashford, Reports of Imp. Cancer Research Fund).

A year ago the discovery of a tumor strand and of a stem structure in secondary tumors in leaves gave a strong impetus to this view. In the interim this contention has been expressed publicly several times (vide Science, Feb. 2, 1912, and Centralb. f. Bakt. 2te Abt., 1912). The bulletin here offered is in the nature of supporting evidence.

This view received only a cool welcome at first, very likely through more or less inapt presentation, but recently it has received respectful attention. In October, 1910 (Int. Cancer Congress, Paris), Jensen, of Copenhagen, expressed similar views respecting a tumor on the sugar beet.

In the meanwhile, on the animal side several publications of prime importance, all within the year, or very nearly, have tended strongly to unsettle the crystallizing belief in the nonparasitic origin of cancer. These have been as follows:

(1) The announcement by Peyton Rous (Jan. 21, 1911) that a chicken sarcoma is inoculable in the absence of living chicken cells, i. e., with fluid freed from the ground sarcoma by centrifuging, and also by filtration through moderately coarse Berkefeld bougies. Fine bougies will not serve. Later, in the Journal of Experimental Medicine, he furnished what seem ample proofs of this contention. Very recently he has shown that tumor material dried for six months is still infectious. (April 4, 1912, An. Meeting Am. Asso. for Cancer Research.)

(2) The discovery by von Dungern that when a round-celled sarcoma of the dog was grafted on the fox *only fox cells grew*. (Muenchner Med. Wochenschrift, Jan. 30, 1912, p. 238.)

(3) The recent statements by Wassermann, Keyser and Wassermann, that cancer cells of mice (both carcinoma and sarcoma) have a selective affinity for salts of selenium when these are passed into the blood stream in combination with eosine, thus showing that the contents of tumor cells is chemically distinct from that of normal cells. (Deutsche Med. Wochenschrift, No. 51, Dec. 21, 1911, p. 2389).

## CROWN GALL A NEOPLASM.

That we have in crown gall peculiarities of neoplastic growth which remove it from all ordinary plant diseases and place it in the category of the true tumors (atypical blastomas) is the burden of this bulletin.

The phenomena of growth in this disease are in the highest degree surprising and are quite unlike anything hitherto known in plant pathology. It is believed for reasons that will become evident further on that for comparable phenomena we must turn to animal pathology, and particularly to that part of it which deals with malignant tumors. Among the latter only do we find growths which appear to be identical. In other words, the contention of this bulletin is that crown galls are to all intents and purposes cancers.

The histological evidence on which this statement is based is presented in the following pages in the form of photomicrographs, only so much text being appended as shall serve to make the sun pictures intelligible. Accompanying these photomicrographs are photographs of the inoculated plants, introduced to show relation of parts. It is believed that more can be learned as to the nature of this disease from an inspection of these pictures than from any number of pages of text, because texts and even drawings are liable to be colored more or less by the beliefs of the writer, whereas the camera reproduces only what is present, albeit sometimes rather imperfectly.

The morphological likeness of crown gall to malignant animal tumors consists in—

(1) A peripheral growth of tumor cells out of preexisting tumor cells, with absence of any capsule or well-defined limit to growth. The growth is injurious and extraphysiological, and, exactly as in human cancer, the cell itself is the only visible parasite.[1]

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[1] "We can say, then, that cancer is not due to a specific parasite or parasites, but, on the other hand, we can say that cancer cells themselves act as parasites. This view will explain all the phenomena of cancer."—*Dr. Charles Powell White.*

"The whole basis, objective and theoretical, of the cancer parasite has been traversed again and again, with the uniform conclusion of those who finish the journey that the cancer parasite is the cancer cell."—*Dr. James Ewing, in his Cancer Problems.*

"*Cancer bodies.*—There exists, in fact, a very remarkable series of localized degenerative changes in cancer cells that have been the cause of active controversy for now close upon 20 years; nor can it be said that the controversy is as yet at an end, although the main body of pathologists of all countries is now of the opinion that these appearances are degenerative and not parasitic. For some years, however, the parasitic theory of cancer had active and enthusiastic supporters."—*Adami, Principles of Pathology, vol. 1.*

(2) The existence of a well-developed supporting stroma.

(3) The formation of tumor strands which extend from the primary tumor in various directions.

(4) The development on these tumor strands of secondary tumors which have the structure of the primary tumor even when they are located in other organs.

(5) The existence of giant cells, i. e., cells which contain several nuclei, and of rapidly proliferating anaplastic cells.

(6) The occurrence of many amitotic nuclear divisions and of occasional abnormal mitotic divisions, i. e., divisions in which more chromosomes pass to one pole than to the other.

## TUMOR CELLS FROM TUMOR CELLS.

A study of the growth of the crown gall shows that certain cells which have received the initial stimulus (infected needle pricks in our experiments) divide repeatedly and often very rapidly (Bul. 213), giving rise to a mass of soft tissue which is not inclosed in a capsule but grows peripherally, infected mother cells giving rise to daughter cells, and so on, indefinitely. These cells also stimulate other uninfected cells into rapid growth. Unlike the reparation of a wound, the growth is not limited to the physiological needs of the plant, but continues removed from the control of the plant except in so far as it is dependent on the latter for its food and water supply.

Apparently any meristematic cell may originate such tumors, but if they are not provided with a stroma they remain small and soon perish. This conclusion is based on a series of shallow versus deep inoculations into daisy stems. When the needle punctures were only 0.5 mm. deep, i. e., only into the region of the cork cambium, a stroma appeared, but the nodules remained small, and rotted away within a few weeks. When the needle pricks were 1 mm. or more in depth, i. e., when they entered the cambium region of the stem, much larger and longer-lived tumors resulted and these were abundantly vascularized.

## GIANT CELLS.

Multinucleate cells occur which are perhaps comparable to the giant cells of the animal histologist. Cancer specialists have divided these into two groups, viz, foreign-body giant cells in which the stimulus is some introduced foreign substance, and genuine ones in which no foreign bodies are visible. There is probably no real distinction other than that those occupied by parasites are malignant and those induced by non-living granules are harmless. The cells in question in crown gall are not very large, but they contain several nuclei. Four nuclei in one cell is the most we have seen, but it is probable that larger numbers occur.

It would seem from our studies, which, however, are incomplete, that most of the cell divisions in crown gall are by mitosis. Frequently, however, we have found nuclei variously lobed and in process of amitotic division, and this is probably the way in which several nuclei are formed in one cell. (See fig. 1 and top figure of Pl. CVIII.) The whole subject of the cell mechanics of the tumor is reserved for further study.

## THE STROMA.

*Pari passu* with the growth of the tumor cells new supporting tissues are developed in the tumor in various places. These supporting

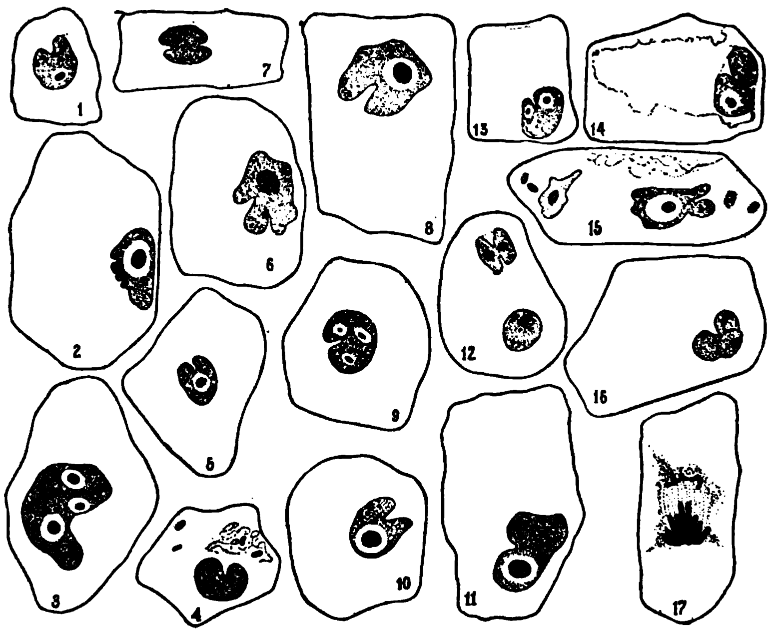



FIG. 1.—Nuclear divisions in crown gall: Nos. 1 to 16, cells showing stages of amitotic division; No. 17, mitotic division in which more chromosomes have passed to one pole than to the other. Material fixed in Flemming, and stained with Heidenhain's iron hæmatoxylin.

tissues consist of pitted vessels and wood fibers, but frequently the latter are scanty or absent. Sieve tubes are also present and are conspicuous in the outer part of secondary tumors. Spiral vessels are sometimes present in the tumor tissue, but never as *new growths*. They occur only as fragments ruptured from their normal position and carried away by the overwhelming growth of the tumor tissue.

A most interesting question arises here: Does the stroma originate in the tumor, or is it a growth from the surrounding tissues? Studying the origin of the pitted vessels in secondary tumors it seemed at first as if they must be derived from the already existing leaf trace

stimulated into abnormal development by the presence of the tumor strand, but such is not usually the case. They are developed in most instances, so far as we have been able to determine, out of the tumor strand itself. Wood fibers when they are present, and likewise the sieve tubes, originate in the same way. This should not seem strange, since the tumor strand is an actively growing meristematic tissue. In some cases, however, the extreme edges of the cambium of the leaf trace seem to proliferate tracheids, which enter the tumor. Further studies will be made.

That the pitted vessels of the stroma are *new growths* admits of no doubt whatever. Their number in secondary leaf tumors far exceeds the normal number in the leaf trace, often as much as 100 to 1, and in early stages of development, such as that shown on Plate XLVIII, we have succeeded in tracing the abnormal vessels into the tumor strand, finding tracheids on one side of the abnormal meristem and sieve tubes on the other side, the tissues of the leaf trace being either uninvolved or only slightly affected. The pitted vessels found in the tumor serve to furnish it with water for its growth. This growth, when the stroma is abundant, forms a very hard, slow growing, fibrous, and resistant mass. But often the galls are soft and much exposed to decay, and in such cases the stroma is scanty and the woody part of it composed only of scattering pitted vessels unsupported by wood fibers. There are all sorts of transitions between these two conditions.

## THE TUMOR STRAND.

Soon after the appearance of a primary tumor, particularly if the plant is well nourished and growing rapidly, tumor strands push out of it into the normal tissues, generally, it would seem, along lines of least resistance. These, of course, are invisible externally, but may be found by dissecting the basal parts of the tumor, and if of any size they are readily detected without the use of the microscope, i. e., by their peculiar structure and color (daisy). Subsequently when they are extending in thin leaves they may be recognized sometimes by a slight tumefaction on the midrib or leaf vein, which ceases beyond the advancing tip of the strand; and especially by the development on the strand of secondary tumors hidden at first by the overlying normal tissues of the leaf but soon giving to the latter a puffed-up appearance and subsequently coming to the surface of the plant by crushing and rupture of the overlying parts. Secondary tumors are a very common phenomenon in the Paris daisy and always, so far as observed, they are outgrowths from the deep-lying tumor strand, which is itself an outgrowth of the primary tumor.

This tumor strand in the Paris daisy makes its way exclusively, so far as observed, in the protoxylem region of the plant, i. e., in the

region of the primitive spiral vessels, where it is often under great pressure, especially in the stem. (Pl. LXII.) So far as known, the tissues under pressure are not absorbed, but they are often flattened, crushed, split open, and exfoliated by the growing tumor. In a tobacco stem a tumor strand was observed in the bark parenchyma. In a number of instances we have found short tracheids in process of development directly from cells of the tumor strands, their lignification being yet incomplete and their nuclei still present. (Pl. LXVIII.)

### STRUCTURE OF SECONDARY TUMORS.

If this disease were a granuloma we should expect the secondary growths to take on the structure of the organ in which they are located but such is not always the case.

When primary tumors develop in the top of beet roots, the secondary tumors in the midrib of the leaf have the many-ringed structure of the root. Usually when primary tumors develop on the soft stem of a Paris daisy secondary tumors appear in the leaves after a few weeks, and these tumors have a distinct *stem structure*—a structure which is not that of the leaf but of an invading destructive growth. This growth appears in one or more of the leaf traces, first as a tumor strand. This strand proliferates a variety of tissues—pitted vessels, sieve tubes, wood fibers (?), and medullary rays. These new vessels make the stroma of the tumor which, by fusing with the leaf trace, causes that part of the leaf to assume the form of an imperfect, rather fleshy, perishable *stem*, the tumor strand occupying the center.

This is such a peculiar phenomenon and so unlike anything hitherto known in plant diseases that the reader might well be excused for scepticism; the statement, however, is well supported by many observations and admits of no doubt, as may be seen from the accompanying photomicrographs.

### ETIOLOGY OF THE TUMOR.

The cause of this disease is a schizomycete, *Bacterium tumefaciens* Smith and Townsend. The proofs of this statement, together with the morphological and cultural characters of the organism were given *in extenso* in Bulletin 213, Bureau of Plant Industry, and will not be rehearsed here.[1] Earlier papers also may be consulted. The organism was described and named after careful determination of its pathogenic properties April 26, 1907 (vide Science, n. s., vol. 25, p. 672, and Centralb. f. Bakt., 2 Abt., XX Bd., p. 89). Following the chart of the Society of American Bacteriologists, the group number of this organism is 212.2322023.

[1] Copies of Bulletin 213, Bureau of Plant Industry, U. S. Dept. of Agriculture, issued Feb. 28, 1911, may be had from the Superintendent of Documents, Government Printing Office, Washington, D. C. Price 40 cents. Add 10 cents for postage to foreign parts.

LOCATION OF THE BACTERIA.

The bacteria causing this neoplasm are located inside the cells, and it is the stimulus of their presence which causes the cell to divide abnormally by throwing it out of balance. Probably this stimulus also extends to many surrounding uninfected cells.

Since we have known the peculiarities of our organism it has been possible to prove, by means of agar poured plates, that the bacteria occur not only in the primary tumor but also in the secondary tumor and in the connecting tumor strand. By means of subcultures from single bacterial colonies we have produced the tumor hundreds of times (Bul. 213, p. 133), but it has not been easy to demonstrate the bacteria microscopically in the tissues. In most plant diseases of bacterial origin hitherto investigated (and the senior writer has been engaged in their study for more than 19 years) the demonstration of the bacteria in the tissues is a comparatively simple affair for any one possessed of fairly good technique. Not so here. We have believed for a long time that the locus of the bacteria must be the interior of the proliferating cells, because high powers of the microscope show that in rapidly proliferating tissues exactly like those known by the poured-plate method to contain the organism there are no granules (bacterial or other), either in the intercellular spaces or in the vessels, except sometimes near the entrance of the needle. Now if an organism is known to be present in one of three places and is not present in two of them, it must occur in the third. Both by diffusion from thin sections and by poured plates we have proved the bacteria to occur in the tumor, and if they do not occur between the cells or in the vessels, and the microscope shows that they do not, then *they must occur* within the cells. There is no other alternative unless we suppose them ultramicroscopic, i. e., totally unlike their form on culture-media, and also unlike the rods and Y-shaped bodies that diffuse out of the sections. (Fig. 2.) Then, of course, they might occur anywhere. Moreover, for such proliferation phenomena as that here described, extending as it does in a narrow cord of cells long distances from the primary tumor, it appears to be absolutely essential to the understanding of the mechanism of the controlling cell divisions that the stimulus should come from within the cell.[1] And that it does come from within admits of no doubt. First, as we have said, because there are no bacteria in the vessels or spaces between the cells; second, because we have occasionally seen rod-shaped, jointed, bacteria-like bodies moving about slowly within the living cells; third, because in a few instances we have been able to see them sharply delimited in

[1] It is inconceivable to the writer that a foreign organism, by any localized and brief presence in the tissues, should so modify cell inheritance that, after the organism and its products have disappeared, the cells should continue to develop abnormally rather than return to their normal habit.

stained preparations (Pls. CV, CVI, and CVII), and have not been able to find similar bodies in rapidly growing healthy tissues treated in the same way; and fourth, because the bacteria occur in the tumor strand and in the secondary tumor (evidence of colonies on poured plates and successful inoculations with subcultures therefrom).

The difficulty of demonstrating bacteria within the cell lies in the fact that commonly they are not very numerous and are mixed in with various cell inclusions which also stain with all the common bacterial stains, and some of which interfere with their satisfactory identification. No one who has not investigated the minute structure of the cell under high powers of the microscope knows the difficulties which lie in the way. The organism stains readily when taken from cultures, but practically all of our attempts to differentiate it in thin sections using the common basic anilin stains have been failures.

As in leprosy, these bacteria are in the protoplasm of the cell, *but not within the nucleus.* This seems to be made out with sufficient certainty by means of gold chloride impregnations which have given beautifully clear pictures, i. e., a farrago of granules (gold precipitates) and small groups of rod-shaped bodies resembling bacteria (some in division) stained deeply in the protoplasmic sac with the nucleus absolutely free and pale almost to invisibility. The protoplasm of the cell outside of the nucleus likewise remains colorless. By counterstaining with eosine the protoplasmic masses and the cell walls also become well defined. With the substage diaphragm wide open the granules are brown dots of various sizes, while the bacteria are deep blue-black rods, often crooked, or in clusters, pairs, chains, short filaments, or involution forms such as occur in culture media. When the diaphragm is closed the granules become paler (a gold color), but the bacteria retain their deep blue-black color. Sixty such rods were counted in the field from which figure 1 of Plate CV was photographed.

The group of bacteria shown in figure 1 is in the interior of a section 15$\mu$ thick. Figure at right is from same spot as 1, at a different focus. It shows 8 bacteria, 4 out of focus. As many as 100 bacteria have been seen within a single cell, all beautifully sharp (vide Plate CVI), but usually we found a lesser number and frequently none whatever, as though only a portion of the cells were occupied by them. Indeed, it would seem from our preliminary studies as though less than 1 per cent of the cells of the tumor are actually occupied by the bacteria. We hope to discuss this phase of the subject more fully in a subsequent bulletin.

By nitrate of silver impregnations we have also stained bodies within the cell which appear to be bacteria, and occasional cells show these in large numbers, but most of them only sparingly. In general, this method, which we tried first, seems less good than the gold chloride method.

The best preparation yet obtained for showing cell inclusions, which are not bacteria but might easily be mistaken for bacteria and were so mistaken by us at first, is a very thin section ($5\mu$) stained by Gram but washed in amyl alcohol. This leaves the violet-blue stain in many kinds of bacteria from which the ethyl alcohol of the true Gram's stain removes it, *Bact. tumefaciens* in cultures being one of these. It was therefore thought to be well adapted for demonstrating them in the tissues. The material from which this section came was fixed in a moderately strong Flemming. The section was stained deeply and washed until very little color remained in the tissues. Most or all of the stained bodies at first suspected of being bacteria are probably lenticular chloroplasts seen on edge. These divide in the same way as bacteria, but they are not rounded at the ends. They can be distinguished from the latter also by the fact that they are not clustered and are circular and pale when not seen edge on. In the sections they show when seen on edge the same intensity and hue of color as the nucleus. These bodies are shown in Plates CVIII and CIX. Many times at least they appear to lie embedded in the wall of the protoplasmic sac (Pl. CIX). Sections stained with Heidenhain's iron haematoxylin also show these bodies very well.

One of the best evidences of the occurrence of the bacteria in the cells is the demonstration of Y-bodies, since there is nothing likely to assume this form in the normal cells of the plant. In Bulletin 213 (p. 107) we figured and described Y-shaped bodies which were obtained from cultures of *Bact. tumefaciens*. These occur in cultures exposed to low temperatures, to sodium chloride, to acetic acid, or to the by-products of the growth of the organism in the presence of peptone and sugar. They are fairly common in old cultures and are not unlike those assumed by many other bacteria when subjected to adverse conditions, e. g., bacteria occurring in the root nodules of legumes. At that time we believed them to occur also in the plant and to be responsible for the slow initial development of the poured-plate colonies (Bul. 213, p. 168), but had not found them. We have now found them *in situ* in the cells of the tumor (Pls. CV, CVI, and CVII) and have obtained them both from the sugar beet and from the daisy by allowing thin sections of fresh tumors to diffuse in water (double distilled from glass) on sterile slides (fig. 2). There is no doubt whatever as to their occurrence in the cells of the tumor, and we now have a sufficient and satisfactory explanation for the often observed slow development of the bacterial colonies on plates inoculated directly from the tumor (vide Bul. 213, pp. 22, 108, 168), because it is a well-known fact that involution forms are either dead or so reduced in vitality as to be slow to resuscitate. Those we obtained by adding dilute acetic acid to young agar and bouillon cultures were

either dead when tested on agar poured plates or developed colonies slowly.

## TWO HYPOTHESES.

I. *Hard versus soft galls.*—Whether a crown gall shall develop as a hard gall or a soft gall would seem to depend chiefly if not altogether on which meristem cells receive the initial impulse. If the cells first

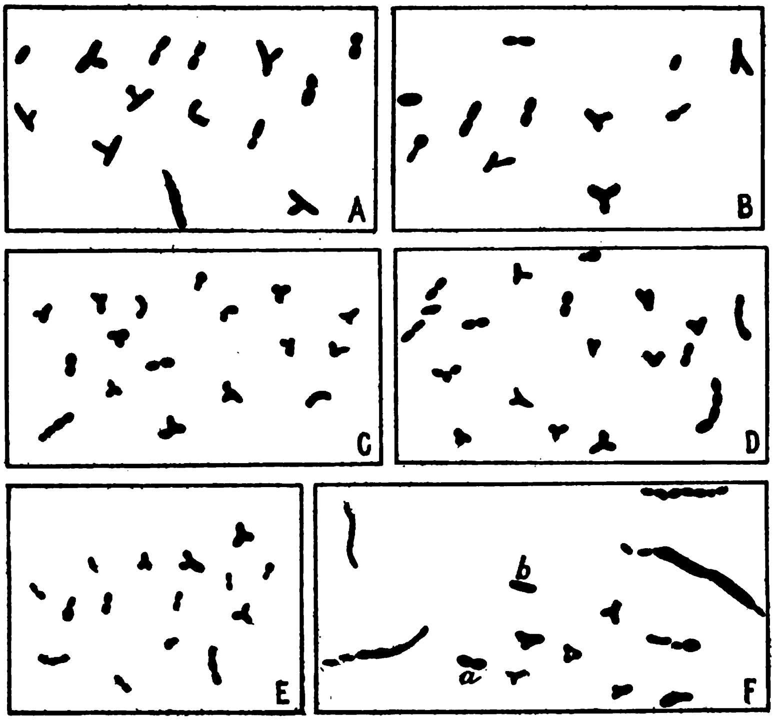



FIGURE 2.—Free-hand drawings of rods and involution forms of Bacterium tumefaciens made in 1911 from young tumors, the slides being obtained by allowing sections of the galls to diffuse for an hour in distilled sterile water, after which they were removed, the fluid on the slides evaporated, and the residue stained 20 to 30 minutes in a dilute solution of basic fuchsin. The surface of the gall was removed with red-hot knives before making the sections, and all of the instruments and fluids were free from bacteria: *A*. Daisy on daisy, May 25 (Brown). About 1 sq. cm. examined in 2 hours; *B*. Daisy on daisy, May 23 (Brown), 2 sq. cm. of slide examined during 5 hours, several other Y's seen; *C*. Hop on red table beet, May 20 (Brown); *D*. Hop on red table beet, May 19 (Brown); *E*. Hop on sugar beet, May 18 (Smith). The rods were about 1.5 to 2 $\mu$ x 0.5 to 0.7 $\mu$. There was not more than one distinct one per field (2 mm. Zeiss 1.30 n. a. oil im. obj. and No. 8 comp. oc.). Frequently one of the two segments of a pair was swollen. More than twice as many involution forms were seen as drawn. There was about one to every 8 or 10 fields. About 10 sq. cm. of the slide were examined. *F*. Hop on sugar beet, slide XXX, May 19 (Smith). Another part of *E*. Eight Y's not drawn. All well stained with diaphragm wide open; *a* measured 1.3 x 0.8 $\mu$; *b*, 3 x 0.5$\mu$, the latter was by itself, i. e., free from other granules with perfectly sharp margins and a deep stain.

infected are principally the mother cells of medullary rays, we may assume that the gall will be a "soft gall," and readily inclined to decay. If, on the contrary, the needle or other carrier of infection wounds principally those meristem cells which give rise to tracheids and wood fibers, the gall will be a "hard gall," of slow growth and long

duration. This hypothesis would seem to account for all the histological differences observed in crown galls and for at least a part of their recognized gradations in virulence.

II. *Crown gall a symbiosis.*—The relation between host and parasite in this disease may be regarded as a symbiosis in which the bacterium has the advantage. It derives its food from the cells of the host, and drives them at a breakneck speed. It gives to them in return its waste carbon dioxide for the use of their chloroplasts. It does not destroy the cells of the host, but only stimulates them into an abnormal and often exceedingly rapid division. This stimulus, it would seem, takes place through the following delicate adjustment of opposing forces: Within the host cell the sensitive parasite produces as one of its by-products an acid. As this accumulates it stops the growth of the bacteria and destroys a portion of them, without, however, destroying the host cell. The membranes of these dead bacteria, which have now become permeable, allow the diffusion into the host cell of bacterial endotoxines. The host cell now contains, of abnormal bacterial products, (*a*) these escaped endotoxines, (*b*) a certain amount of weak acid (acetic?), (*c*) some ammonia, and (*d*) an excess of carbon dioxide. Under the stimulus of one or more of these poisons the nucleus divides by mitosis. In process of division the nuclear membrane disappears and the contents of the nucleus flows out into the cell. The dormant bacteria under the stimulus of this nuclear substance renew their activities in the daughter cells until again inhibited, whereupon the daughter cells divide. By this rocking balance, in which first the parasite and then the host cell has the advantage, the tumor develops rapidly and independently of the needs of the plant.

The facts underlying this hypothesis are as follows:

(1) *Evidence from pure cultures.*

(*a*) The development of Y-shaped and other involution forms in pure cultures of *Bact. tumefaciens*, subjected to unfavorable conditions.

(*b*) The development of an acid in sugared peptone water cultures, to the action of which acid the involution forms are attributed.

(*c*) Our ability to produce these Y-shaped bodies at will and promptly in young agar and bouillon cultures by addition of small quantities of dilute acetic acid.

(*d*) Proof from agar-poured plates that most or all of the Y-bodies developed in the presence of the acetic acid are dead, i. e., will not grow into colonies when copious sowings are made on agar plates.

(*e*) The observation that those bacteria which are not killed by exposure to the acid are so paralyzed that they come up more slowly on agar-poured plates than do those from untreated cultures.

(*f*) Production of ammonia by this organism in culture-media as one of the results of its assimilation of nitrogen compounds.

(*g*) While *Bact. tumefaciens* does not give off $CO_2$ in measurable quantities in fermentation tubes in the presence of sugar, it is assumed that such large volumes of the gas are not only not requisite but would be injurious to the mechanism of tumor development, and that all ordinary bacteria, including this one, throw off some $CO_2$ as a result of their growth.

(2) *Corresponding evidence from the plant.*

(*a*) To obtain *Bact. tumefaciens* from the tumors by means of agar-poured plates unusually heavy sowings must be made.

(*b*) These colonies often come up slowly as if the bacteria from which they have developed were nearly dead and must first recover from some inhibition before they can grow. Once recovered they grow satisfactorily.

(*c*) The existence of good-sized Y-bodies and variously deformed bacteria in the tumor tissue as shown by their diffusion from sliced tissues lying on flamed slides in bacteria-free water.

(*d*) Proof from ordinary sections, stained and unstained, that the bacteria do not occur in the vessels or the intercellular spaces of the tumor. There are no bodies of any sort in these places.

(*e*) Demonstration by impregnation with gold chlorid that the bacteria are not abundant in the tissues, that they occur *inside the cells but outside the nucleus*, and that Y-bodies and variously branched forms are common.

(*f*) The existence of an excess of $CO_2$ in the tumor cells is inferred from the behavior of the chloroplasts which multiply in the tumor strand and other deep parts of the tumor in large numbers so as to make the tissues decidedly green.

(*g*) A statement by the chemist that the same acid occurs in tumor tissue as in our flask cultures.

Up to this time we have not been able to determine the litmus reaction of the nucleus; neither have we been able to show conclusively that the acid produced in the tumor tissue is identical with that developed from grape sugar in our flask cultures. The uranium salts look much alike, but I am not sure that they are identical. Further studies will be made.

## EFFECT OF CHROMATES.

Ever since we have known this neoplasm to be due to bacteria lodged within the cell, it has been a foregone conclusion that, however much the tumor cells might resemble meristematic or embryonal tissues morphologically, their chemical contents certainly must be somewhat different both on account of the by-products thrown off during the growth of the bacteria and by reason of reactions set up by the cells against the intruding organisms. In Bulletin 213, page 173, it was shown that the tumor tissue (sugar beet in that case) contains

an excess of colorless substances oxidizing to dark compounds on exposure to the air. A further evidence of chemical difference is shown on Plate CIV. In figure 1 of this plate the deeply stained pieces represent portions of a daisy tumor soaked in water saturated with potassium bichromate. The unstained pieces are normal parts of the daisy treated in the same way. The brown stain appears slowly in cold solution but within a few minutes in hot ones. Potassium chromate and neutral ammonium chromate have the same action on the galled tissues, staining them a deep brown, whereas the normal meristematic tissues are only feebly stained. Chromic acid and chrome alum did not have this effect. The substance which causes this dark stain may be extracted from the tissues readily by hot alcohol, as shown in figure 2 of Plate CIV. Here the right-hand sections were exposed for a few minutes to the action of a hot saturated solution of potassium chromate. The sections at the left were from the same tumor and were treated in precisely the same way, except that they were first thrown into hot ethyl alcohol and allowed to simmer for a few minutes. That some substance is actually removed from the tissues is shown by the subsequent behavior of the alcohol in presence of these compounds of chromium. This reaction was discovered in making experiments to determine whether the appearance of the gold chloride preparations might not be improved by some preliminary treatment. It was hoped that a way might be found to remove some of the substances causing granular precipitates within the cell and so leave a clearer picture. Naturally we first thought of tannins. What this soluble substance is remains to be determined. Possibly it is a tannin, in which case the brown reaction might perhaps be considered as a phlobaphene reaction due to the acid radicle of the salts used.

## NOTES ON TECHNIQUE.

The daisy plants described in the following pages are plants selected from a series inoculated especially for the purpose of studying the movement of the tumor strand and the development of stem structure in the leaves. All were inoculated at about the same time, a foot or more above the earth, and all in the young, rapidly growing stems, except those plants used for checks, i. e., those inoculated on the leaves. All of the inoculations were made by needle pricks without hypodermic injection. At the time of the inoculation the stems were soft and rapidly elongating, and the needle pricks were made in what was then the top of the plant. For inoculating material we used agar subcultures from single poured-plate colonies. All of the inoculated plants contracted the disease where pricked and not elsewhere, except as the result of invasions from the primary tumor.

We obtained a great wealth of pathological material of which only a part could be used for the preparation of this bulletin. The material selected for the sections was fixed in Carnoy's fluid (acetic acid 1, alcohol 3). Suitable pieces were then infiltrated with paraffin, cut on the microtome, usually in series, fastened to clean slides with egg albumen, and stained in various ways, none of which, however, demonstrated any bacteria in the tissues, i. e., not with certainty. We sometimes saw rods in these sections but could not be *sure*.

Many stains were tried. The best stain for differentiating lignified from nonlignified tissues proved to be that recommended by Chamberlain (Methods of Plant Histology, pp. 49 and 68), i. e., a prolonged stain in methyl green followed by a short exposure to acid fuchsin.

The photomicrographs were made on Hammer's double-coated nonhalation orthochromatic plates using monochromatic light (Zettnow's fluid). They were made with Zeiss apochromatic objectives and a No. 4 compensating ocular. All of the photomicrographs except a few at the end were made either with the Zeiss 16-millimeter or 8-millimeter objective. The source of the light was an electric arc. The developer used was rodinol, usually 1 part to 30 parts of water. The exposures were made by the senior writer, but the plates were developed and printed from by Mr. Brewer.

## NORMAL ANATOMY OF THE DAISY.

So much will be said about abnormal phenomena in the stems and leaf traces of the daisy that some words of introduction are necessary respecting the microscopic structure of the normal plant, especially for those not familiar with the anatomy of plants.

### STEM.

In the center of the stem is a *pith*. This is composed of nearly isodiametric cells which, as growth continues, become compressed in various directions by pressure of neighboring cells so that on cross section they are often hexagonal. This tissue, while remaining alive for a considerable period, remains dormant and functions chiefly as a storage system. At the periphery of the immature stem is a cylinder of coarse-celled, rather loose tissue known as *bark parenchyma*. The young stem is covered and protected from the air by a one-celled layer known as the *epidermis*, between which and the bark parenchyma one or more layers of cells with thickened angles may be present. This is known as *collenchyma* and functions as a strengthening tissue. Finally in this region a tissue develops which is known as the *cork cambium*. As the stem grows this cork cambium proliferates (slowly on the daisy), giving rise to layers of impervious cells (*cork*) which take the place of the thin, temporary epidermis. Between the bark parenchyma and the pith is a complex structure consisting of a series

of elongated *bundles* radiating from the pith in every direction. These are few in number at first and separated by wide areas of looser tissue (Pl. I), but very numerous as the stem grows, and then separated by narrow, compressed plates of nearly isodiametric cells known as *medullary rays*. In the young stem these rays extend from the pith to the bark parenchyma. In older stems new ones arise from time to time and take their origin at more and more remote distances from the pith. Bordering these bundles externally, i. e., on the inner border of the bark parenchyma, is a layer of cells known from its contents as the *starch sheath*. The bundle consists principally of wood and soft bast or *xylem* and *phloem*, in the terminology of the anatomist. The structure in detail of a single bundle in such a stem is as follows: The xylem portion consists, at its older (innermost part), of a few *spiral vessels*, which do not increase in number; beyond these are *pitted vessels* (tracheids) and *wood fibers* (wood parenchyma) which are continually increasing in number as the stem grows. The phloem consists of *sieve tubes* (slime vessels) and *companion cells*. The longer axis of these vessels corresponds to that of the stem. As the stem increases in size *bast fibers* (groups of thick-walled elongated cells) appear in the outer part of the bundle not far from the phloem, i. e., inside the starch sheath. The phloem is separated from the xylem by the *cambium* which also separates the xylem part of the medullary ray from its phloem part. The cambium is the most actively growing part of the stem, giving rise to new bundles and increasing the size of the old ones, xylem tissues being laid down on the inner side of it and phloem tissues on the outer.

Plate I shows a cross section of a healthy portion of Daisy No. 1, branch II, from epidermis to pith. Beginning at the top, the tissues occur in order as follows: *E*, epidermis; *cc*, subepidermal layer; *cp*, cortical parenchyma with chloroplasts; *st*, starch sheath; *bf*, group of bast fibers; *p*, phloem; *c*, cambium; *t*, *sp*, xylem wedges (tracheids and spirals), which are heavily stained; *mr*, medullary ray; and *pt*, pith. As the stem increases in diameter the wood wedges become numerous and compacted into a thick cylinder, and then the epidermis is slowly replaced by bark. Section stained with methyl green and acid fuchsin.

Plate II shows in cross section a part of branch III, Daisy No. 1. Here the ring of wood is somewhat thicker, and the bast fibers are also more abundant. For appearance in cross section of the older stems containing a much greater quantity of wood, see Plates XXI, XXV, LXIII, LXVII, and LXXVIII.

When leaves or branches are given off from such a stem they include parts from all the various elements of the bundle as mentioned below.

### LEAF TRACES.

Those vascular portions of the stem which pass out into leaves are known as *leaf traces*. In the daisy petiole there is a central leaf trace and several side ones. Farther out (on the lamina of the leaf) these leaf traces branch repeatedly, forming a supporting and conducting network, the so-called *veins* of the leaf. The appearance of a normal leaf trace in cross section is shown on Plate III. Beginning at the top of the plate (under surface of the petiole), the tissues occur in order as follows: *par*, loose parenchyma or ground tissue of the petiole; *st*, starch sheath, entirely surrounding the bundle; *scl*, thin-walled elongated supporting cells; *p*, pholem; *c*, cambium; *t*, tracheids of the xylem; *m*, medullary ray; *sp*, spirals of the xylem; *scl*, thin-walled elongated supporting cells; and *par*, surrounding loose-celled parenchyma of the petiole. On Plate IV may be seen the appearance of a similar leaf trace in longitudinal section, the top of this plate corresponding to the top of the preceding. Below the large spiral vessels are smaller spiral vessels and delicate ring vessels. It is through this region that the tumor strand passes. Plate V shows the appearance of a longitudinal section through a petiole between two leaf traces, i. e., through the ground tissue of the leaf from epidermis to epidermis. Portions of this tissue are often surrounded by and incorporated into the growing tumor.

The function of the xylem part of the bundle, aside from support, appears to be storage and movement of water; that of the phloem, storage and movement of elaborated nitrogenous substances. The pith and medullary rays are often used as starch receptacles. The bark parenchyma contains numerous chloroplasts whose function it is to convert water and carbon dioxide into sugar and starch. The pith, young wood fibers, and medullary rays also contain chloroplasts but in lesser numbers.

In considering the abnormal phenomena now to be described these plates illustrating the normal anatomy will be of prime importance.

## BEHAVIOR AND HISTOLOGY OF SELECTED PLANTS SPECIALLY INOCULATED FOR THESE TESTS.

### DAISY NO. I.

#### WHOLE PLANT.

(Plate VI.)

This plant was inoculated January 13, 1911, and photographed March 10, 1911. Primary tumors developed at *x*, where punctured. Secondary tumors afterwards appeared on leaves *A*, *B*, *C*, and *D*, as shown. After photographing, agar poured plates were made from the interior of each one of the branches (I, II, III) to determine

whether the inoculated organism could be isolated therefrom. Plates were also poured from the secondary tumors on *A*, *B*, and *C*. Finally, portions (marked *F*) of the three branches and of leaf *C* were fixed, embedded, sectioned, and stained for demonstration of the tumor strand, if such existed.

The poured plates were as follows:

*A* (not burst through), 8 plates (Brown).
*B* (burst through), 5 plates (Hedges).
*C* (burst through), 7 plates (Brown).
I, 8 plates (Brown).
II, 6 plates (Hedges).
III, 7 plates (Brown).

Total, 41 plates. All negative or doubtful. One of the colonies which came up on the twelfth day from stem I looked hopeful and was transferred, but there is no record of inoculations.

The histology of the parts is shown in the following plates.

### Branch III.

(Plate VII.)

Cross section of branch III, slide 575 C 1, in the lower part. This section shows the junction of wood and pith with a small tumor strand in the center of the picture. This strand passes from the primary tumor into petiole *C*. Section torn in mounting. For a normal part of the same section, see Plate II. For longitudinal sections of *this* strand farther away from the primary tumor, i. e., in the petiole, see Plates XVII to XX.

### Petiole C.

(Plates VIII and IX.)

Cross section of petiole *C* (Pl. VIII), at one end of the lower fixed portion (slide 643 A 18), showing the enlarged and modified central leaf trace. The traces on either side of this one are normal. The parenchyma between the leaf traces is also normal, but is somewhat shrunken by the fixing agent.

In Plate IX the upper part of the middle leaf trace, slide 643 A 19, is enlarged to show the tumor strand. For a similar section from the other end of the fixed part of this petiole, see Plates X and XI, which should be compared with Plate III.

### Petiole C.

(Plates X and XI.)

*Plate X.*—Cross section of central leaf trace at other end of the fixed portion of petiole *C*, slide 643 B 6, showing abnormal wood wedges. The original leaf trace is at the lower and left part, some-

what enlarged and distorted, but otherwise nearly unchanged. The upper portion of this leaf trace enlarged to show the tumor strand may be seen in Plate XI, made from another slide in the same series (643 B 12).

BRANCH I.

(Plates XII, XIII, and XIV.)

The varying appearance of the tumor strand at various levels in the same series of sections is well illustrated in Plates XII to XIV, made from branch I under petiole *A*. (See Pl. VI.) Here the tumor strand (block 575 A, slides 8, 10, and 11) is in the inner wood next to the pith. In Plate XII it consists exclusively of small cells. In Plates XIII and XIV there are also in it large soft cells with very conspicuous nuclei. In Plate XIV, in the lower part of the strand, are tracheids developed from cells of the tumor strand and twisted at right angles to their normal direction. This is a common occurrence.

BRANCH II.

(Plate XV.)

Cross section of branch II, slide 575 B 10, just under petiole *D*, showing a somewhat irregular tumor strand in the xylem part of the bundle. In the lower part of it, near the pith, are twisted tracheids developed from the tumor strand. Above is infiltration.

PETIOLE C.

(Plate XVI.)

Tumor tissue from petiole *C*, slide 643 C 39, showing many cells with 2 nuclei. It is all rapidly proliferating parenchyma, but the cells are growing in different directions.

PETIOLE C.

(Plates XVII, XVIII, and XIX.)

Plates XVII to XIX are sections of the upper portion of the fixed part of petiole *C*, i. e., they are the same as Plates IX and XI, but cut longitudinally to show the extension of the tumor strand. The plates were made from block 643 *c*, slides Nos. 23, 21, 19, and 17. The top of the plate represents the proximal part of the petiole. The strand, which comes from the stem, has developed the small unruptured tumor *M* (Pl. VI), and thence passed into the part here shown. The small, rapidly proliferating neoplasm shown at the bottom of Plate XVIII is not yet large enough to be indicated by any surface swelling. In XVII and XVIII, *x* corresponds to *x*. The distal part of the strand in greater detail is shown on Plate XX.

### PETIOLE C.

(Plate XX.)

Plate XX shows a longitudinal section of petiole *C*, one field beyond Plate XIX, i. e., its top joins on to the bottom of Plate XIX. In the center of the plate is the tumor strand, to the left are spiral vessels, to the right is a portion of the tissue marked "scl" in Plate III, with which, and Plate IV, this should be compared.

## DAISY NO. II.

### CROSS SECTION OF STEM.

(Plate XXI.)

One of the plants inoculated January 13, 1911, and fixed March 23, 1911. This plate gives a cross-section of the stem, slide 641 A 13, between the primary tumor and a secondary one and shows a well-developed tumor strand on the lower right-hand side at the junction of wood and pith. The wood is enlarged a little near the strand, but otherwise it is normal. The bark is also normal. The pith cells are flattened next the tumor strand by pressure, but farther away are normal. For a detail see next plate.

### TUMOR STRAND IN STEM.

(Plate XXII.)

Plate XXII, from slide 641 A 13, gives an enlargement of the tumor strand shown on Plate XXI. The black dots are nuclei. The figure shows a vague demarcation at the top where the tumor strand shades into the modified wood, and a sharp one below where the pith cells are flattened by pressure. At *sp.* are several rows of crushed spiral vessels; at *X*, *Y*, *Z*, are displaced spiral vessels. This section was stained with methyl green and acid fuchsin.

## DAISY NO. V.

### WHOLE PLANT.

(Plate XXIII.)

This plant was inoculated January 13, 1911, and photographed March 27, 1911, three-fourths natural size. Primary tumor at *X* where the needle pricks were made. Secondary tumors on leaves *A*, *B*, and *C*. Both *A* and *C* have split open. Several small roots were projecting from the base of the primary tumor on this side, but are hidden by the apex of leaf *B*. For the back view of this plant, see Plate XXIV.

WHOLE PLANT, BACK VIEW.

(Plate XXIV.)

Plate XXIV gives the opposite side of the plant to that shown on the preceding plate. *A* and *C* correspond. *B*, which has been shortened to a stub, is invisible. At *D* are secondary tumors in the base of a leaf, the remainder of which has shriveled under the influence of the disease. Four leaves on this side between *C* and *A* were free from visible growths. They were removed before photographing for clearness sake. Roots stimulated into development by the presence of the tumor are present at *RR*. The stem between *E* and *F* was removed; photographed end on, at *F* (see lower left part of the plate); and then split longitudinally, along the median line (see lower right part of plate). In the middle of the vertical section is an expansion of the green tumor strand which later on might have burst through the wood and bark and appeared as a surface tumor. Secondary stem tumors of this sort are now present in the hot houses. The cross section shows enlargement of the wood on one side and a distinct green tumor strand between wood and pith. For the minute anatomy of the stem at this level, see Plate XXV.

CROSS SECTION OF STEM.

(Plate XXV.)

Cross-section of stem, slide 594–8, at the level of *F* in Plate XXIV, showing the large tumor strand with thickened wood cylinder on that side only and absence of thickening in the bark. Under a hand lens the duplication of medullary ray cells near the strand may be seen in the photograph but is lost in the half tone. The pith is normal except in the vicinity of the tumor strand where it is flattened.

Section stained with Ehrlich's acid hematoxylin. The strand is redder than the other tissues.

For details from the tumor strand see Plates XXVI and XXVII.

A DETAIL FROM THE TUMOR STRAND.

(Plate XXVI.)

Plate XXVI, from slide 594–8, gives more highly magnified the upper portion of the tumor strand shown in Plate XXV. At the left are the cells of the tumor strand; at the bottom, top, and right side is the modified wood. The demarcation between the modified xylem and the tumor strand is somewhat vague. The black dots are deep-staining nuclei.

DETAIL FROM THE TUMOR STRAND.

(Plate XXVII.)

Plate XXVII, from slide 594–8, gives the lower part of the tumor strand shown on Plate XXV. The cells of the tumor strand are at the right. The pith is at the left and its cells have been flattened by

the pressure. The demarcation between the tumor strand and the pith is sharp.

## DAISY NO. VII.

### Whole Plant.

(Plate XXVIII.)

This plant was inoculated on January 13, 1911, and photographed March 31, 1911, about two-thirds natural size. The bacterial culture was introduced at *X X*, where the primary tumor soon developed. Secondary tumors developed on leaves *A*, *B*, *C*, *D*, and *E*, and also in the interior of branches I and II. Material at *F* was fixed for microtome sections from stem I and from leaves *A* and *D*. Petri-dish plates were poured from the interior of *A*, *B*, *C*, and D. Pieces from the interior of I and II were also transferred to tubes of bouillon and incubated.

The plant was 8 months old and 24 inches high. It divided into two equal branches, both of which were inoculated. One branch only is shown in the photograph (for notes on the other one see below). The inoculation was made 11 inches from the ground. The actual distances at the time the photograph was made were as follows: Origin of leaf *A* to primary tumor, 6 cm.; length of infected portion of leaf *A*, 9 cm.; origin of *A* to base of *B*, 5.5 cm.; base of *B* to its tumor, 4 cm.; total distance from primary tumor to tumor on *B*, 15.5 cm.; time, 77 days; top of *C* to origin of branch bearing it, 5 cm.; origin of *D* to junction of II with main stem, 4 cm.; length of secondary tumor on *D*, 6 cm. At *Y Y* the petioles in cross section are circular and resemble stems, i. e., they have a narrow green pseudopith, a wide ring of wood, and beyond this a cambium and phloem. All that distinguishes *D* as a petiole are the unchanged petiole wings. For the appearance of microtome sections from these petioles see the following plates.

Both above and below the swelling on I there is a thickening of the wood on one side, and in the inner part of this next to the pith is a green strand of tumor tissue about 1 mm. in diameter.

The following are notes on the inoculated branch which was not photographed:

The primary tumor is now 2 by 1.5 inches in diameter. The main axis has been dwarfed by the growth of the primary tumor to a tiny shoot 3 inches high. This is 2 to 3 mm. in diameter, except at the base, which is much swollen by an internal tumor not yet ruptured to the surface (this part is 1 cm. in diameter). Four centimeters above the base a leaf arises which bears secondary tumors in the midrib for a distance of 5 cm. Under the primary tumor, coming out of the wood and bark is a cluster of nine small roots. On the back side, in the same relative position, are eight other small roots.

The primary tumor has also grown into the base of three other shoots as follows: (1) Right-hand shoot, arising from the middle of primary tumor, where all but the base of the shoot has been destroyed, the latter being occupied by a living tumor 3 cm. long and 2 cm. broad. (2) Left-hand shoot, arising near base of primary tumor, bears a ruptured tumor for a distance of 4 cm. and thence appears sound externally for a distance of 10 cm., where it gives off a leaf that at a distance of 7 and 8 cm., respectively, from its junction with the stem, shows on the midrib two unruptured secondary tumors, the remotest one being, therefore, 22 cm. from the primary tumor and 17 cm. from any surface indications of disease. (3) In the middle back part of the primary tumor a stem arises which shows no surface tumors, but is swollen and bears two leaves with secondary tumors, diameter of stem at base being 5 mm., but 2 cm. up (in swollen place) it is 8 mm. in diameter. The first diseased leaf arises at a distance of 5 cm. up and shows ruptured tumors for a distance of 6 cm. on the midrib. Two centimeters farther up the second leaf arises and this bears secondary tumors on the midrib for a distance of 2 cm.

The tumor stimulus has extended down the main stem, but much less conspicuously. It is visible for a distance of 8 cm. below the main tumor, as shown (1) by a root pushing out 3.5 cm. below, and (2) by a small secondary tumor in a leaf scar 8 cm. down. Here the stem is 1.5 cm. in diameter and quite woody. In a hasty examination I could find no tumor strand in the interior of this hard stem.

The cultures were negative or doubtful, as follows: Petiole *A*, no gall colonies; petiole *B*, no gall colonies; petiole *C*, one gall colony, daisy inoculation therefrom negative; petiole *D*, no gall colonies; stem I, no gall colonies on plates poured from three tubes after clouding; stem II, after six days very suggestive stringy filaments in both tubes. Plates from one gave only pink colonies, plates from the other gave colonies which for a time very much resembled the daisy organism, but we finally rejected them as intruders. Two of the four tubes of II inoculated with large pieces of the stem never clouded (17 days), and also one of the four of stem I.

### Petiole A.

(Plate XXIX.)

Plate XXIX, from slide 592 B 17, gives the base of petiole *A* in cross section, showing conversion of the central leaf trace and two side traces into secondary tumors having stem structure. A tumor strand occupies the center of each modified leaf trace. The only unchanged parts of the petiole are the periphery and the marginal wings. The primary xylem of the leaf trace occupies about one-fourth of the present wood cylinder, i. e., that on the right side.

For a detail from the center of the middle tumor see next plate. Section stained with methyl green and acid fuchsin.

### Petiole A.

(Plate XXX.)

Plate XXX, from slide 592 B 17, gives the center of the middle leaf trace from Plate XXIX enlarged to show the character of what may be called the pseudopith, i. e., the rapidly proliferating tumor strand, in the center of the pseudostem. Woody tissues at top and bottom. In the lower right corner an abnormal medullary ray.

### Petiole D.

(Plate XXXI.)

Cross section of petiole *D*, slide 592 A 15, showing conversion of the petiole into a secondary tumor which has not yet ruptured to the surface. Stem structure plainly visible. Several infected leaf traces have fused. The central tumor strand is conspicuous. The margins of the petiole are not involved; but for these no one would suspect this to be a petiole. The actual diameter of the mounted section is 8 mm. The primary xylem of the leaf trace appears to be on the lower right hand side. Section stained with Ehrlich's acid hematoxylin.

## DAISY XI.

### Whole Plant.

(Plate XXXII.)

This plant was inoculated January 13, 1911, and photographed April 5, 1911, about three-fourths natural size.

The primary tumor, *X*, *X*, induced by needle pricks, surrounds the stem except as here shown. Secondary tumors developed after some weeks on *A*, *B*, *C*, and *D*. Leaf *D* has shriveled to a stub. The growth in *A* has ruptured to the surface but not in *B* except near the apex. The terminal part of *B* was removed earlier for study. On dissection a green strand of soft tumor tissue was traced from the primary tumor into both *A* and *B*. The petiole *B* in the vicinity of *M* was found to have stem structure in the middle leaf trace and was fixed for sections (Pl. XXXIV). In the main stem at *P*, i. e., just under the attachment of leaf *C*, a green strand of tumor tissue was visible under the hand lens, but was inconspicuous. For the appearance of this strand when more highly magnified see Plate XXXIII.

### Cross Section of Stem.

(Plate XXXIII.)

Plate XXXIII, from slide 591 AA 3, gives a cross section of the stem at the lower line of *P*, i. e., just under origin of the infected leaf *C*. It shows an abnormal soft tissue strand in the wood somewhat farther away from the pith than customary. The vessels of the single row below this strand are spirals. Pith cells at the bottom. Stained with methyl green and acid fuchsin.

### Petiole B.

(Plate XXXIV.)

Plate XXXIV, from slide 591 B 8, gives a cross section of base of petiole *B* showing stem structure in the central leaf trace. In the center of this tumor is the tumor strand; to the right is the original xylem of the leaf trace more broken up and disorganized than in Plate LII, i. e., there appears to have been an invasion of soft cells from the tumor strand or a stimulus to increased development of the medullary rays from proximity to that strand. In other directions may be seen the abnormal wood wedges separated by wide areas of nonlignified tissues—medullary rays, etc. Beyond is cambium and beyond that phloem. At the extreme right beyond (outside) the phloem are a few thin-walled pitted vessels in what appears to be a small modified misplaced leaf trace, or portion of such a trace.

The small black specks in the central strand are normal and crushed spiral vessels wedged off from the base of the primary xylem of the leaf trace by the growth of the tumor tissue. These appear to be a portion of the original spirals of the leaf trace. All the *new* vessels forming the abnormal wood wedges are tracheids, i. e., short pitted vessels. These are stained blue in the section and are dark in the photograph.

### Petiole B.

(Plate XXXV.)

Plate XXXV, from slide 591 B 6, gives the middle portion of the modified middle leaf trace of petiole *B* at about the same level as Plate XXXIV, enlarged to show the character of the tumor strand which contains both pitted vessels and spiral vessels. The primary wood wedges of the leaf trace are in the upper right hand corner. Projecting into the tumor-strand from this part crushed spiral vessels may be seen. Section stained by Gram-eosin.

### Petiole B.

(Plate XXXVI.)

Plate XXXVI, from slide 591 B 2, gives a cross section of the middle portion of the infected leaf trace of petiole *B* in vicinity of *M*, showing two of the three whorls of small cells surrounded by tracheids.

These are on that margin of the tumor strand remotest from the primary xylem of the leaf trace. They are not visible on Plate XXXV. Section stained with methyl green and acid fuchsin.

In the middle of the figure on the right side are tracheids twisted at right angles to their normal direction.

## DAISY XII.

### WHOLE PLANT.

(Plate XXXVII.)

Plant inoculated by needle pricks on January 13, 1911, and photographed April 5, 1911, nearly natural size. Primary tumor, *X*, *X*, mostly on the reverse side of the plant where pricked. Secondary tumors on petiole *A*, which has ruptured, and on *B*, which has not yet broken open. Behind *A* was a third leaf occupied by secondary tumors and now shriveled to a stub. In cross section at *M* the petiole *A* shows stem structure, i. e., a green pseudopith, greenish wood cylinder (complete), cambium ring, and phloem. In the lower part of the picture (magnified about 2 diameters) is a cross section of petiole *A* where at *X* and *Y* are shriveled remnants of the wings of the petiole. This may be compared with the earlier stage shown in Plate XXXIV and the still earlier stage on Plate XLVII. Here the petiolar tissue outside of the tumor is entirely destroyed. Although *A* is circular in cross section at *M* and has a diameter of 9 mm., it is attached to the stem by a small, shriveled pedicel, i. e., the remnant of the petiole base. The stem was split along the vertical line and then cut crosswise at $O$ to $O^3$.

At the level of *O*, deep in the stem, was a soft, green strand of tumor tissue nearly circular and about 1 mm. in diameter, proceeding from the primary tumor toward *A*. Under the microscope this appeared to be totally unlike either wood or pith. It was on the tumor side of the stem in the wood, but near the junction of wood and pith. This tumor strand was also visible to the naked eye or with the hand lens at $O^2$ and $O^3$, but not at $O^1$. However, when fixed, embedded, sectioned, stained, and examined under the compound microscope, it was visible here also (see Pl. XXXVIII). For appearance of petiole *B* in cross section at various levels, see Plate XLII and the following ones.

### CROSS SECTION OF STEM.

(Plate XXXVIII.)

Plate XXXVIII, from slide 590 $C^1 1$, gives a cross section of the stem at $O^1$ (see Pl. XXXVII), showing a tumor strand at the inner border of the wood next the pith. Some of the pith cells at the bottom of the picture are shriveled, owing to the fact that the stem

segment was cut diagonally and these cells border on the extreme edge of the cut. Above this strand, in a vertical line, is a row of spiral vessels (walls stained blue). On a right line with these in the lower part of the strand is a lignified vessel of another type (tracheid), the blue wall being represented by a wide black border (it is the immature cell containing an elliptical nucleus). The walls of the other bordering cells and of the strand cells in the section are stained red. Other sections in this series also show tumor-strand cells in process of conversion into pitted vessels.

Section stained with methyl green (for the xylem) and acid fuchsin (for the protoplasm and cellulose walls).

PETIOLE A.

(Plates XXXIX and XL.)

Frequently inside a tumor several proliferation centers of soft, small cells may be seen surrounded by whorls of tracheids, as shown in Plates XXXIX and XL, made from different areas in the same slide (590 A 7). Cut at right angles to sections here shown, they appear as strands, and which often pass out toward the surface of the growth. There are two of these whorls in petiole *A* at the level of this section. They are near the center on that side of the tumor strand (Pl. XLI) remotest from the original xylem wedges of the leaf trace. The top of each picture is toward the periphery of the tumor, and they join onto each other (*X* corresponding to *X*) and also join on at their bottom to the top of Plate XLI, which shows the tumor strand.

PETIOLE A.

(Plate XLI.)

Plate XLI, from slide 590 A 2, gives a cross section of the central part of the secondary tumor in petiole *A* (Pls. XXXIX and XL), showing rapidly proliferating large cells of the tumor strand, containing spirals (the thick-walled cells). At the bottom and left the innermost elements of the wood wedges are visible. The bulk of the xylem is below, the wood cylinder being open and imperfect above.

PETIOLE B.

(Plate XLII.)

Plate XLII, from slide 590 B 13, shows a cross section of petiole *B* in the vicinity of fig. 13 (Pl. XXXVII). Above, below, and at the left are the unchanged petiolar tissues. In the center and at the left is the enlarged central leaf trace, preserving nearly its normal form (compact tissue at left of center). At the base of this, in the

center of the section, is the tumor strand, radiating irregularly from which may be seen additional abnormal wood wedges. Toward the right may be seen masses of small-celled tumor tissue inclosing numerous unmodified cells of the loose parenchyma of the petiole. There are also tracheids near *X* and *X*. The leaf trace next under this one is also distorted. For a detail of the tumor strand see next plate.

PETIOLE B.

(Plate XLIII.)

Plate XLIII, from slide 590 B 10, gives the central part of a section from nearly the same level as the preceding (Pl. XLII), showing (in the center) the large soft cells of the tumor strand at the base of the primitive wood wedges of the leaf trace. The larger cells below are inclusions.

PETIOLE B.

(Plate XLIV.)

Plate XLIV, from slide 590 B 16, shows a cross section of the secondary tumor in petiole *B* at some distance from fig. 13 (Pl. XXXVII), Here the tumor strand is larger and the abnormal wood wedges are more prominent than on Plate XLII. For a detail of the tumor strand see next plate.

PETIOLE B.

(Plate XLV.)

Same as preceding plate (i. e., from slide 590 B 16), but the central part more highly magnified to show the character of the central tumor strand. The bottom of this picture corresponds to the left of the preceding. In the upper part of the strand is a whorl similar to those shown on Plates XXXIX and XL. At the right of it is an unmodified medullary ray consisting of one row of small cells and below this a modified one consisting of several rows of large soft cells. The tumor strand contains both large and small celled parenchyma.

PETIOLE B.

(Plate XLVI.)

Plate XLVI, from slide 590 B 19, shows a cross section of the middle leaf trace of petiole *B* beyond any visible swelling, i. e., somewhere near figure 19, Plate XXXVII. Here the secondary tumor is reduced to a comparatively small mass of tissue, i. e., to the tumor strand at the base of the xylem wedges, and a small mass of tissue below it. For appearance at the lower end of this petiole see the next two plates.

PETIOLE B.

(Plate XLVII.)

Plate XLVII, from slide 590 B 24, shows a cross section of petiole *B* near its base, i. e., at about the level of figure 24, Plate XXXVII. The external shape of the petiole is about normal, the upper surface of it being at the right. Only the central leaf trace is here diseased, for details of which see next plate. Section stained by Gram-eosin.

PETIOLE B.

(Plate XLVIII.)

Plate XLVIII, from slide 590 B 24, gives enlarged the middle leaf trace from the preceding plate, showing the beginning of the pseudostem (secondary tumor). In the center is a group of soft cells forming the tumor strand. This consists of mixed tissue, many of the cells being isodiametric or only slightly longer than broad, while others are more or less elongated. Above is the leaf trace slightly modified, i. e., showing in its lower part infiltration of soft cells from the tumor strand, wedging apart the spiral vessels. Below are abnormal wood wedges and connective tissue. The vessels of this part are tracheids. On the outer edge at *S* are groups of sieve tubes. To determine the origin of these abnormal wood wedges the remainder of the petiole was sectioned longitudinally, i. e., downward toward the stem. (See Pl. XLIX.)

PETIOLE B.

(Plate XLIX.)

Longitudinal section, slide 590 $B_2$ 21, of abnormal part of leaf trace shown in Plate XLVIII. Beginning at the bottom we have: *sp*, normal spirals of the leaf trace; *tstr*, tumor strand; *scl*, normal supporting cells of the leaf trace; *tr*, abnormal tracheids developed from the tumor strand; *tp*, tumor parenchyma; *inc*, included cell, i. e., one of the large cells of the loose parenchyma of the petiole.

PETIOLE B.

(Plate L.)

Cross section of petiole B, slide 590 B 4, of Plate XXXVII, showing abnormal lignification of the walls of four of the included cells. These are large cells of the loose parenchyma of the petiole, like those shown in Plates XLII and XLIV. They have taken a deep blue stain (lignin), whereas the walls of similar cells below are pink (cellulose). Section stained with methyl green and acid fuchsin. Such abnormal lignification of parenchyma cells is not infrequent.

## DAISY NO. XIII.

### Whole Plant.

(Plate LI.)

This plant was inoculated on January 11, 1911, and photographed April 6, 1911, seven-eighths natural size. The inoculations were by needle pricks at *X*, *X*. The stem is swollen in the vicinity of the primary tumor. *A* and *B* are leaves bearing secondary tumors. *B* is directly over the right side of the primary tumor and 8 cm. away. The secondary growths on this leaf which have split it open in places extend outward a distance of 10 cm., making a total extension from the primary tumor of 18 cm. in 54 days. The stem between *A* and *B* is normal externally, except that at the level of figure 2 on a vertical line between the primary tumor and *B* there is a very slight swelling of the stem over the location of the tumor strand.

The internal condition between the right side of the primary tumor and *B* in a straight line is as follows: At 1, slightly thickened wood ring on the right side and a half dozen aggregated tiny spots at the junction of the wood and pith where the tissue is stained greener (best seen in thin section). At 2, the green strand under the swollen wood is more conspicuous and measures 1.5 mm. wide by 0.7 mm. thick (photographed slightly enlarged); see the lower part of this plate. At 3, the wood is not conspicuously enlarged and the strand is not visible under the hand lens. At 4, the strand again shows. Shaved tangentially between 3 and 4, we could not distinguish the tumor strand clearly by its green color.

### Petiole B.

(Plate LII.)

Plate LII, from slide 589–3, gives a cross section of petiole *B* near its base, showing a secondary tumor in the central leaf trace, which is greatly enlarged and converted into a pseudostem. In its center is the tumor strand; at its right is the nearly normal xylem of the leaf trace. Radiating from the tumor strand in other directions are the abnormal wood wedges with broad bands of soft cells between them. The tumor is beginning to rupture to the surface on the left side. The cells of the petiole immediately surrounding the tumor are flattened by pressure. Gram-eosin stain. For a detail from the center of the tumor at this level, see next plate.

Longitudinal sections were made through the central leaf trace and sieve tube tissue demonstrated on the periphery of the tumor in nearly all of them.

### Petiole B.

(Plate LIII.)

Plate LIII, from slide 589–12, gives the tumor strand and surrounding tissues from petiole *B* at the same level as Plate LII, enlarged to show in detail the character of the tissues. The black dots are nuclei. Sections stained with Ehrlich's acid hematoxylin. The tumor-strand has stained much redder than the surrounding tissues.

## DAISY NO. XIV.

### Whole Plant.

(Plate LIV.)

This plant was inoculated January 11, 1911, at *X* by needle pricks, and photographed April 6, 1911, three-fourths natural size. Leaves *A*, *B*, *C*, and *D* bear secondary tumors. The distance from the base of *A* at the top of the primary tumor to the origin of *D* is 6.5 cm. The length of the secondary tumor on *C* is 10 cm., that of the ruptured part, 6 cm. The structure of *C* in cross section is that of a stem with a complete wood cylinder, on one side of which is unchanged petiole structure (see Pl. LV). The tumor strand is sometimes in a central leaf trace and sometimes as at *B* and *D* in side traces.

At the level of fig. 2 there is a thickening of the wood and a green stain under both *B* and *C*. At 3 this is less conspicuous. At both of these levels, as seen under the microscope, the area of disturbance is not large, and both it and the green stain were confined to the inner wood next the pith.

Poured plates were made from the interior of *C* above the lower fixed portion and these yielded typical gall colonies in small numbers. On April 19, with agar subcultures from one of these colonies, five young daisy plants were inoculated. At the end of 20 days galls were forming on them at all of the inoculated places. Cultures from this colony into peptonized beef bouillon also gave the typical strings or filaments.

### Petiole C.

(Plate LV.)

Plate LV, from slide 593 A 13, gives a cross section of petiole *C*, showing three of the leaf traces involved in a secondary tumor which has ruptured to the surface at the bottom and right and which shows a distinct stem structure, the wood wedges being separated in places by conspicuous plates of modified soft medullary rays (for a detail of these see Pl. LVI). Unmodified petiole tissue occurs at the left and at the top. Above the tumor strand in the lowest leaf trace is a wedge of tracheids in the outer portion of which the longer axis of the

vessels extends parallel to the surface of the cut and tangential to the stem. Slide stained with methyl green and acid fuchsin.

PETIOLE C.

(Plate LVI.)

Plate LVI, from slide 593 A 22, shows a cross section of a small part of the secondary tumor in petiole *C*. At the left is a wood wedge with tracheids of normal arrangement, at the right is a wood wedge with tracheids twisted at right angles to the normal direction. Between these two is an abnormally broad medullary ray composed of soft rapidly proliferating cells, several of which contain two nuclei. In portions of such plates the ray cells (?) are twisted so that their long axis is parallel to the surface of such a cut as that here shown, i. e., like the right wood wedge. Section stained with methyl green and acid fuchsin.

PETIOLE C.

(PLATE LVII.)

Plate LVII, from slide 593 A 22, shows in cross section a woody part of the secondary tumor in petiole *C*, not far from the tumor strand. The central loosely arranged soft cells are possibly modified ray cells. They take the fuchsin stain less deeply and are much larger than the cells of the tumor strand (see next plate) which is below and at the right just outside the limits of this plate.

PETIOLE C.

(PLATE LVIII.)

Plate LVIII, from slide 593 A 22, shows a cross section of the middle part of the secondary tumor in petiole *C*. In the center is the tumor strand. This consists of small rapidly dividing cells which have stained heavily with the acid fuchsin. Surrounding this is a small portion of the pseudostem (for orientation see center of Plate LV). At *A* and *B* are modified medullary rays; at *C* and *D* are woody tissues twisted in abnormal directions. In this plate and the preceding one, *D* corresponds to *D* and the magnification is the same.

PETIOLE B.

(PLATE LIX.)

Plate LIX, from slide 593 B 2, gives a cross section of petiole *B*, showing a secondary tumor with stem structure in *X*, a lateral leaf trace. The leaf trace next below it is also slightly involved, as may be seen more clearly from Plate LX. The rest of the petiole appears to be normal.

### Petiole B.

(Plate LX.)

Plate LX, from slide 593 B 6, gives in cross section a portion of petiole *B*, showing the leaf trace next under *X* of Plate LIX. Here the abnormal phenomena is restricted to distortion of the bundle with the separation of a few tracheids from their fellows, the twisting of others at right angles to their normal directions, and the appearance below of wedges of soft tissues.

## DAISY XVI.

### Whole Plant.

(Plate LXI.)

This plant was inoculated by needle pricks on January 13, 1911, and photographed April 10, 1911, nearly natural size. Primary tumor at *X* where punctured. Secondary tumors at *A*, *B*, *C*, *D*, *E*, and *F*. At *B* and *D* are stubs of leaves removed earlier for study and from the cut surface of which tumors have developed. At *C*, *E*, and *F* are remnants of leaves destroyed by the tumor. On section the base of *A* was found to have a stem structure.

In the stem, under *A* and leading up to it, was a green strand of soft tumor tissue. This was situated at the junction of wood and pith, but mostly in the wood. It continued beyond *A*, i. e., at fig. 2 on the vertical line, and still more conspicuously at 3, but less so at 4; it was visible as a small mass of soft, deep green parenchyma. There was a similar strand under *C*. On cross section this strand pushed out 0.5 mm. as though it had been under great pressure (see Pl. LXII). It contained so many chloroplasts that it was very green in comparison with the color of the wood and pith.

### Stem and Leaves.

(Plate LXII.)

Figures *A* and *B* are enlargements of the stem between tumors: *A* gives a cross section of stem at the level of fig. 3 (Pl. LXI) under leaves *E* and *F*, showing a nearly circular strand of soft green tumor tissue with the woody cylinder conspicuously thickened on that side. The difference in color enabled us to get a photograph showing marked contrasts. ×2.

*B* is the same as *A*, but somewhat further enlarged and photographed obliquely to show more clearly the pushing out of the tumor strand on removal of the pressure.

These are photographs of the specimen exhibited at the meeting of the American Association for Cancer Research, Buffalo, N. Y., April 13, 1911.

Figures *C* and *E* are enlargements of the reverse side of petioles *C* and *E* (Pl. LXI), showing how these deep-seated secondary growths have split open the petiolar tissues and come to the surface. In cross section these growths appear as a flattened imperfect woody cylinder. Photographed April 10, 1911. ×3.

### Enlarged Cross Section of Stem.

(Plate LXIII.)

Plate LXIII, from slide 586 A 15, gives a cross section of the stem at the level of fig. 2 (Pl. LXI), showing the tumor strand and a conspicuous enlargement of three-fourths of the woody cylinder. The strand is the dark area on the left side of the pith. The section was torn a little in mounting.

### A Portion of the Tumor Strand.

(Plate LXIV.)

Plate LXIV, from slide 586 A 30, gives an outer portion of the tumor strand in cross section. It is at the same level as Plate LXV, but from another part of the strand. In the upper and left-hand part are distorted tracheids. The spiral vessels except the few mentioned below are at the right beyond this field.

### A Portion of the Tumor Strand.

(Plate LXV.)

Plate LXV, from slide 586 A 30, gives the inner margin of the tumor strand in the stem, showing the stroma (pitted vessels) originating in the tumor tissue. Below this field is the pith; at *S*, *S*, are spiral vessels of the normal stem widely separated from their fellows by the intrusion of the tumor strand. The remainder of the spiral vessels lie in the direction of the arrow the width of another whole field away.

## DAISY NO. XVII.

### Whole Plant.

(Plate LXVI.)

This plant was inoculated January 13, 1911, by needle pricks on the stem and photographed April 10, 1911, natural size. Primary tumor at *X*, *X*, where punctured, portions of it beginning to decay. At *A*, *B*, *C*, and *D*, are leaves showing secondary tumors. *A* and *C* are affected only at the base; *B* is diseased through a length of 10 cm.; *D*, which was removed earlier for study of its tumors, has a tumor projecting from the cut surface, i. e., an outgrowth of the diseased leaf trace. The stem at *F* was fixed for sections. The tumor in *C* was also fixed. It showed stem structure at its base.

Petiole *B* showed an imperfect woody ring. The petiole was split open below at *Y* with tumor tissue protruding the same as shown in Plate LXII from plant XVI. Under *B* in the stem at *E* there was a wedge-shaped thickening of the woody ring and a distinct green tumor strand in the inner wood. Plate LXVII made from the stem at the level of *F* shows a smaller tumor strand passing toward *D*.

### Cross Section of Stem.

(Plate LXVII.)

Plate LXVII, from slide 639 A 19, gives a cross section of the stem at one end of *F* (see preceding plate), showing a small tumor strand passing to leaf *D*. This is in the inner wood jutting into the pith in that portion of the woody ring (lower part at *X*) which is thickened a little. This thickening was more conspicuous a half centimeter farther down, i. e., under *B*. For a detail of this strand see Plate LXVIII. The diameter of this section is 7.5 mm. The dark places in the bark are normal.

### Tumor Strand in Stem.

(Plate LXVIII.)

Plate LXVIII, from slide 639 A 20, gives a detail from the same level as Plate LXVII, showing (in the center) the tumor strand with tracheids developing in it. This is the more interesting because the vessels immediately above the strand (all shown in this photograph) are spirals. Pith below. Both this section and the preceding were stained with methyl green and acid fuchsin.

### Tumor Strand in Stem.

(Plate LXIX.)

The same as the preceding but cut from the other end of the stem at the level of *F*, slide 639 AA 21. Pith below, wood above, tumor strand in the center. Section torn a little at the bottom.

The vessels of the wood immediately above this strand are spirals. Just below the strand are four spirals wedged away from their fellows by the growth of the strand. There is also one crushed spiral nearer the strand and two or three displaced ones at the left. No tracheids are visible in it or near it.

### Petiole C, Showing Tumor Strand.

(Plate LXX.)

Base of petiole *C*, slide 639 B 10, showing the tumor strand in longitudinal section. Vessels and other tissue lie to either side.

### TUMOR TISSUE FROM PETIOLE C.

(Plate LXXI.)

Tumor tissue from the base of petiole *C*, slide 639 B 5, showing cells with 2 and 3 nuclei. On the right are tracheids mingled with tumor cells. The elongated cells at the left are tumor cells cut parallel to their longer axis. There are probably two types of tumor cells in this section. Stained with methyl green and acid fuchsin.

### INFILTRATION OF TUMOR TISSUE IN PETIOLE C.

(Plate LXXII.)

Margin of a secondary unruptured tumor in petiole *C*, slide 639 B 9, showing infiltration of the tumor cells into the coarse-celled tissue on the periphery of the petiole. The tumor is at the left, the parenchyma of the petiole at the right. In the upper part, at the extreme right, the epidermis *E* is visible. Outer portion of the petiole curved by the internal pressure.

## DAISY No. XVIII.

### WHOLE PLANT.

(Plate LXXIII.)

This plant was inoculated January 13, 1911, by needle pricks at *X*, *X*, where the primary tumor developed, and photographed April 10, 1911, nearly natural size. Secondary tumors developed on leaves *A* and *B*. The tumor on *A* is in a marginal leaf trace. The tumor strand of *B* is in the central leaf trace and six tumors developing from it have reached the surface, the remotest one being 9.5 cm. from the stem. Both branches of this leaf (*X* and *Y*) are diseased. The insertion of this leaf is 2 cm. from the top of the primary tumor at *T*.

Immediately above the primary tumor and under *B*, cross sections of the fresh stem showed the woody cylinder thickened a little on that side. The inner angle of the xylem wedges next the pith was greenish, but there was no conspicuous strand. Under the compound microscope two tumor strands are visible, however, in stained cross sections of this stem.

### PETIOLE A.

(Plate LXXIV.)

Plate LXXIV, from slide 635 B 9, is a longitudinal section of petiole *A*, showing the tumor strand. This plate at its bottom joins on to the top of the next plate.

PETIOLE A.

(Plate LXXV.)

Plate LXXV, from slide 635 B 9, is a continuation of Plate LXXIV, showing the tumor strand expanding at bottom into a small tumor. For a continuation of this see next plate.

PETIOLE A.

(Plate LXXVI.)

The top of this plate, from slide 635 B 11, joins on to the bottom of the preceding plate, but the magnification is somewhat greater. The bulk of the plate (all of the center) is occupied by the tumor in which may be seen four centers of active proliferation.

DAISY NO. XIX.

WHOLE PLANT.

(Plate LXXVII.)

This plant was inoculated by needle pricks at *X*, *X* on January 13, 1911, and photographed April 15, 1911, three-fourths natural size. Diameter of stem at *Z*, 12 mm. Distance from the primary tumor to the insertion of *B*, 3.5 cm. and length of the secondary tumor in *B*, 9 cm. Stem structure at *S*, *S*. Portions of *A* and *B* were fixed in Carnoy's solution and also the stem to either side of 3. The stem between *A* and *B* was normal on the surface except for a slight swelling on the right side at the level of 3. Here on cross section a small green tumor strand in the wood was visible under the hand lens, but not in this manner at 1, 2, or 4.

CROSS SECTION OF STEM.

(Plate LXXVIII.)

Plate LXXVIII, from slide 595 $A_1$ 8, gives a cross section of the right side of the stem not far from figure 3 of the preceding plate, showing a small tumor strand at *X* where the wood is slightly thickened. The remainder of the stem is normal. The bark was torn a little in mounting, and the outer portion of the pith was shriveled by the fixative. Section stained with methyl green and acid fuchsin. For appearance of the tumor strand more highly magnified and a little farther down (or up), see next plate.

CROSS SECTION OF STEM.

(Plate LXXIX.)

Plate LXXIX from slide 595 $A_2$ 1 gives a cross section of the stem a few millimeters away from that shown on Plate LXXVIII and more highly magnified, showing a conspicuous tumor strand in the inner

wood near the pith. This is composed of large, soft, thin-walled cells, easily differentiated from the surrounding cells not only by their *form* but by their behavior toward stains, i. e., the surrounding cells are blue while these are red. Stain: methyl green and acid fuchsin.

PETIOLE A.

(Plate LXXX.)

Plate LXXX from slide 634 D 15 gives in longitudinal section an infected leaf trace at the base of petiole A, showing a conspicuous tumor strand with vessels to either side—spirals at the right. At *X* are cells of the tumor strand undergoing change into tracheids. Stained with methyl green and acid fuchsin. See plate IV for a longitudinal section through a normal leaf trace.

PETIOLE A.

(Plate LXXXI.)

Plate LXXXI from slide 634 A 4 shows a longitudinal section of petiole *A*, like Plate LXXX but farther up the leaf, i. e., the section was made between *Y* and *Y'*. To the left are nearly unchanged vessels of the leaf trace (stained blue in the section); to the right is the large-celled parenchyma of the ground tissue of the petiole. Between the two in the region of the spiral vessels is the tumor strand. Stain: Methyl green and acid fuchsin. Tracheids at *T'*, spirals at *S*, *S*, cambium at *C*, and phloem at *P*.

PETIOLE A.

(Plate LXXXII.)

Plate LXXXII, from slide 634 D 4, gives a longitudinal section through petiole *A* at the level of the unruptured secondary tumor *Y*, showing the stroma of the tumor, i. e., the development of tracheids in the tumor tissue. In the section the tracheids are blue and the tumor cells red. The normal direction of the tracheids is right and left, and in healthy leaf traces and also in the normal parts of diseased ones they are straight and parallel, as shown in the left-hand part of Plate LXXXI. In this section no wood fibers accompany the tracheids.

PETIOLE B.

(Plate LXXXIII.)

Plate LXXXIII, from slide 595 $B_2$ 5, gives a cross section of petiole *B* to show its conversion into a stem under the influence of the tumor strand. The actual diameter of the section is 9 mm. The only unchanged parts of the petiole are the wings *W*, *W*, and a little coarse-celled parenchyma at the left. There is a slight gap

in the woody cylinder (bottom part above *W*), which is bridged over by tracheids which have grown at right angles to their normal direction. On the right side of the rapidly proliferating soft central mass of cells (tumor strand) are four whorls of tracheids inclosing soft cells (see next plate). The large cells to the right of these are portions of the petiole parenchyma surrounded by the tumor tissue and more or less modified by its presence. The dark spot in the upper part of this mass is a cell of the same type in the walls of which lignin has been deposited abnormally. Section stained with methyl green and acid fuchsin.

WHORLS FROM PETIOLE B.

(Plate LXXXIV.)

Plate LXXXIV, from slide 595 $B_2$ 8, gives a cross section of a small portion of petiole *B* at nearly the same level as Plate LXXXIII, showing the character of two of the tracheal whorls on the border of the tumor strand, which lies in the direction of the arrow. One of the whorls contains large cells and the other small ones. Section stained with methyl green and acid fuchsin.

BASE OF PETIOLE B.

(Plate LXXXV.)

Plate LXXXV, from slide 634 B 5, shows a cross section of the extreme base of petiole *B*. Seminormal wood wedges are at the left; abnormal ones at the right; tumor strand in the center. In the middle and on the left margin of this are crushed spiral vessels. Stained with methyl green and acid fuchsin.

## DAISY NO. XX.

WHOLE PLANT.

(Plate LXXXVI.)

This plant was inoculated January 13, 1911, by needle pricks at *X*, *X*, and photographed April 17, 1911, nearly natural size. Primary tumor at *XX*, beginning to decay; secondary tumors on leaves *A*, *B*, *C*, *D*, and *E*. Leaf *A* has shriveled nearly to its base, which is much swollen. Leaf *C*, which bore secondary tumors, was removed earlier for study and now bears a tumor on its cut curface. On *D* the tumor extends as far as *Y*. The distance from *Y* to insertion of *D* is 12 cm. The distance from *Z* to insertion of *E* is 10.5 cm., and from this point to the top of the primary tumor is an additional 2.5 cm.

The dissection notes are as follows: At 1, immediately under *B* (lower figure), the cross section shows a soft green tumor strand

at the junction of wood and pith, with slight enlargement of the wood on that side. The wood is also enlarged under *D*, and a tumor strand also apparently is present here, but not conspicuous; later (Pl. LXXXVII) it was demonstrated conclusively under the microscope. At 2 and 3 there was no distinct enlargement of the wood. Split longitudinally between 1 and 2 the stem showed to the naked eye a green strand narrowing upward and running out near 2.

Material was fixed from *D* and *E* and from the stem below *D*, all of which showed typical invasion.

### Cross Section of Stem.

(Plate LXXXVII.)

Plate LXXXVII, from slide 632 C 3, gives a cross section of the stem below petiole *D*, showing a small tumor strand in the center. Below is pith; above are the spiral vessels of the inner wood, with medullary rays between them. At *X*, *X*, are two spiral vessels separated from their fellows and crushed.

### Petiole D.

(Plates LXXXVIII to XC.)

Plate LXXXVIII, from slide 632 D 8, gives a longitudinal section of petiole *D*, showing the general relations of the small central neoplasm to the petiolar structure. A detail from the upper end of this tumor is shown on Plate LXXXIX, and a section near the periphery of the same tumor on Plate XC. Here the spirals are twisted and wedged apart. Tracheids occur to either side beyond the spirals and also in the tumor tissue at *X*. The nuclei, which appear to be in the spirals, are in tumor tissue under them.

### Petiole D.

(Plate XCI.)

Plate XCI, from slide 632 D 10, gives a longitudinal section of petiole *D*, showing the appearance of one end of a small unruptured tumor developing from the tumor strand. The other end of the same tumor is shown in plate XCII. The two photographs together cover about three-fourths of the tumor.

### Petiole D.

(Plate XCII.)

Plate XCII, from slide 632 D 10, shows a longitudinal section of petiole *D*. It was photographed from the other end of the tumor shown in the preceding plate. The wedged-off tracheids are at the

top. The normal tracheids and the spirals (somewhat displaced and crushed) are at the bottom. For continuation of the tumor strand see next plate (XCIII).

### Petiole D.

(Plate XCIII.)

Plate XCIII, from slide 632 D 10, gives a longitudinal section of petiole *D*, taken one field away from the preceding plate (XCII), showing the continuation of the tumor strand (center) with vessels to either side.

## DAISY NO. —.

### Margin of Tumor in Petiole.

(Plate XCIV.)

This petiole is from one of the plants inoculated January 13, 1911. It was fixed March 6, 1911. This plate, XCIV, from slide 574 A 4, shows the extreme margin of an unruptured secondary tumor, surrounded by and inclosing (*P*, *P*) normal large cells of the petiolar parenchyma. Rather large pieces of the material were fixed in Flemming's fixative *A* for 24 hours, then soaked 24 hours in a hardening fluid consisting of water 99, glacial acetic acid 0.7, and chromic acid 0.3 and washed in running water for 24 hours. The section was stained with methyl green and acid fuchsin. It belongs in this series, but no record was made of the plant number. At *T* is a bit of the stroma (a group of tracheids).

## DAISY NO. XXXI.

### Foliage.

(Plates XCV to XCVII.)

Plate XCV shows the top of a plant inoculated April 26, 1911, in the leaves only by means of single needle pricks. It was photographed June 2, 1911, i. e., at the end of 37 days. Sections of two of these tumors for comparison with secondary tumors in the leaves follow as Plates XCVI and XCVII. The structure consists of a mixture of tracheids with soft-celled tumor tissue. There is no such differentiation of parts as shown in the secondary leaf tumors., i. e., no distinct stem structure.

## HOP ON TOBACCO.

### Pith of Stem, Cambium, Etc.

(Plates XCVIII to CIII.)

An effort was made to determine, by inoculation into young stems of rapidly growing tobacco plants, just which tissues were stimulated to proliferate. While the results from these inoculations are not

entirely conclusive, some very interesting phenomena were observed. It was shown, for instance, in material three weeks inoculated, that there was no proliferation along the needle track *in the pith* (Pl. XCVIII), but an area of proliferation developed in the vicinity of the cambium (Pl. XCIX). Small tumors arose also on the margins of the needle wounds at various levels. Plate C shows one at the mouth of the needle wound and Plate CI shows one about half way from the lips of the wound to the cambium line. Both of these small tumors are well provided with tracheids (*tr*), although they are both growing from the level of the bark parenchyma where no tracheids are normally present. The question here is whether the nodules were developed in place, i. e., out of infected parenchyma or from deeper cells whose progeny have come to the surface. A study of the whole series of sections would seem to indicate the former surmise as the correct one. The presence of tracheids and sieve tubes, $x$, also indicates this. Further studies will be made. In Plates C and CI the needle wound is at the right and the bark parenchyma at the left.

Perhaps the most interesting feature brought out by these inoculations relates to the tumor strand. In all of the daisy inoculations we have seen the tumor strand select the protoxylem region of the stem as the line of least resistance to its movements. In one of the tobacco plants a strand of small-celled tissue originating in the proliferations from one of the infected needle wounds passes through the middle of the coarse-celled bark parenchyma parallel to the surface of the stem, as shown in Plates CII and CIII, which join onto each other, $x$ corresponding to $x$. The arrow indicates the direction of the surface of the stem, which is about 12 cell-layers away. The phloem lies at about an equal distance away from this strand in the opposite direction. This strand can be traced only on slides 23, 24, and 25. It ceases a little beyond the top of the first plate. Above and below these sections is the ordinary bark parenchyma. The strand is sparingly provided with tracheids, the smallest group being at $x^1$. The needle track lies just below the lower tracheids shown in Plate CIII.

## DAISY TUMOR.

### Chromium Reaction.

(Plate CIV.)

Figure 1 of Plate CIV shows the effect of five minutes' exposure to a hot saturated solution of potassium bichromate. The black pieces are slices of a young tumor; the pale ones are longitudinal sections and cross sections of normal young stems of the same plant.

Figure 2, right-hand side, shows the appearance of slices of young tumors exposed for five minutes to a hot saturated solution of potassium chromate. The left-hand colorless sections are pieces from the

same tumor which were extracted in hot ethyl alcohol for a few minutes before exposing to the hot bath of potassium chromate.

## CYTOLOGICAL STUDIES.

(Plates CV, CVI, and CVII.)

Plate CV shows the first results of an attempt to photograph *Bact. tumefaciens* within the cells of the tumor. Lantern slides of these figures were exhibited at Philadelphia, April 4, 1912, before the American Association for Cancer Research. The nuclei are unstained, and counterstained with eosine. Rods and Y's are visible, also many negligible granules. The figures 1, 1 denote different levels in the same cell. The middle figure (branched rod) in the top row of Plate CVII is also from this field. In the lower right-hand figure a Y-body lies on the upper part of the nucleus—outside of it, however.

Plate CVI shows various levels in a single cell, which is nearly or quite free from precipitates and contains numerous bacteria (deep blue-black rods on a colorless ground). Its faint nucleus (*N*) may be seen at the bottom of the left-hand figure of the middle row. Above it in the upper left-hand part of the figure is the conspicuous nucleus of a cell which is free from infection, or nearly so. Owing to the slight penetration of the Zeiss oil immersion lens (3 mm. 1.30 n. a.) eight photomicrographs were made at different levels in this field so as to give as clear a picture as possible. The figures 1, 1; 2, 2; etc., denote corresponding places in the photographs. The bulbous ends of some of the rods, e. g., 2, are illusions due to the fact that only a portion of the rod is in sharp focus. The cell walls are unstained and invisible except with a very narrow pencil of rays.

Plate CVII shows additional rods and branched forms, and absence of these bodies in the nucleus. The numbered places represent slightly different levels in the same cells. The bacteria lie in such irregular positions that it is impossible to have many of them sharply defined at any one focus, e. g., in the lower part of the right-hand figure of the upper row are three rods in a chain, but the lower one is entirely out of focus. The one marked 4 in the lower figure shows distinct branching but had to be made a little vague to get 3. So, also, in the upper left-hand corner of the second figure from the bottom, 5 is distinctly branched but had to be thrown out to get portions of the three rods marked 6. The tumors used for these sections were impregnated in bulk and afterwards sectioned. In their preparation suitable material was sliced from the tumors and put for 24 hours into water containing 5 per cent gold chloride. It was then transferred to 0.25 per cent formic acid and kept in the dark for 24 hours (modification of Löwit's method for nerve fibers), after which it was washed, dehydrated, and embedded in paraffin in the usual way.

To bring out cell walls, protoplasm, and nucleus, some of the sections were subsequently stained on the slide with eosine, a faint stain proving most satisfactory.

(Plates CVIII and CIX.)

These two plates were made from photomicrographs of the $5\mu$ thick section already referred to, which was stained by Gram, and washed in amyl alcohol until very pale. They are introduced to show lenticular chloroplasts which when seen edge-on might be confused with bacteria. The upper figure of Plate CVIII also shows a nucleus in amitotic division (see fig. 1 in text). The dark spot in the center of Plate CIX is a nucleus out of focus. To bring that into sharp focus threw the chloroplasts entirely out of focus.

## ANALOGIES.

The higher plants are much simpler in structure and function than the higher animals and any comparison of the diseases of one with the other must take these facts into account. The plant is much closer to the soil than the animal, i. e., to the inorganic world.

Neither may the higher plants be regarded, like the higher animals, as units. They are rather to be regarded as congeries of such units, one or more of which may be destroyed without injury to the rest. A peach tree, for example, may be split longitudinally and, if care be exercised, the two halves will continue to live as separate trees, the circulation of the two parts being distinct because the movement of fluids, foods, etc., is up and down rather than sidewise. This is illustrated by the fact that if we cut all of the feeding roots on one side of a tree, the other side is not immediately injured, and, if we introduce into the circulation on one side of the trunk some readily diffusible substance, it quickly passes to the top of the tree on that side, but moves around the trunk to the other side only very slowly. If these overgrowths are cancers we might, therefore, expect what we find, namely, that the tree as a whole is less injured by such growths than would be an animal with a unitary structure and a rapid general blood circulation.

For similar reasons structural comparisons of the higher plants and animals is difficult. While such plants and animals are fundamentally alike in that both are composed of living cells multiplying in the same manner, capable of secretion and excretion, and having divided labors but united into a harmonious whole, yet when we come to compare their anatomy and the diverse ways in which the same physiological ends are accomplished, many difficulties arise. There is, for instance, in the plant no muscular system, no nervous system, and nothing corresponding to the complex digestive apparatus of the higher animals. The reproductive apparatus occu-

pies a smaller space in plants and is temporary. Also, to a much greater extent than in animals, the cells which secrete special products are distributed among other cells, rather than grouped together into special organs.

We might, therefore, expect to find in a plant cancer, if such a disease exists, both simplification, and combination of traits which in the animal appear to be peculiar to the tumors of special tissues.

When the writer compared crown-gall to sarcoma it was with such mental reservations as grow out of these differences. In the connective tissue of plants there is no interstitial substance, and therefore we could not expect to find it in a plant tumor derived from such tissues. Their general appearance, therefore, is more like a nontypical epithelioma or carcinoma; so also is the marked cell reaction in their vicinity, viz, increase of wood elements; and the structure of their secondary tumors. But, inasmuch as the round cells appear to be sometimes derivatives from the mother cells of medullary rays and show all gradations from actively vegetative unripe cells into well-developed ray cells forming overgrown medullary plates, and at other times are descendants of certain cells of the bark parenchyma, we may perhaps still regard them as resembling sarcomas. They are also like the latter in their predilection for young plants and the softer, more rapidly growing tissues of older plants, as well as in the luxuriant anaplastic character of their proliferations.

Another difficulty, however, has arisen. At that time I regarded the stroma of such tumors as ingrowths developed from the surrounding tissues under the stimulus of the tumor cells: Recent experiments undertaken to settle this point seem to indicate that the vessels (tracheids and sieve tubes) in part, at least, originate in the tumor directly from tumor cells; i. e., that the tumor-strand is a complex body containing some cells capable of originating vessels and others of a purely vegetative unripe sort.

The experiments leading to this conclusion were shallow pricks into stems. Here the needle did not reach to the phloem, much less to the still deeper cambium, and yet both sieve tubes and tracheids developed in these shallow tumors in tissue which never normally produces them.

In other words, if we have not misread the evidence, under the stimulus of this organism, certain cells of the bark parenchyma (upper part of Plate I) lose their specific features and become small rapidly proliferating purely vegetative (unripe) cells, while others develop tracheids and sieve tubes; i. e., tissues normally developed only by the deeper cambium. A study in serial section of small

tumors thus produced shows an abundant production of vessels in the absence of any wounding of the deeper cambium and in stems where no cork cambium has yet developed. The parenchyma cells of such tumors, as shown by their form, their size, and their behavior toward stains are purely vegetative and quite distinct from the matrix of bark parenchyma cells in which they lie and from some of which they have developed. This ability of cells of the bark parenchyma, which are as well differentiated as those shown in Plate I, to produce undifferentiated blastomous cells, some of which are capable of developing xylem and phloem, was not what we expected to find, but is clearly what the shallow inoculations seem to establish, and this conforms very well to a statement made in Bulletin 213, viz, "It is not yet beyond dispute that a cell mother of one kind can never give rise to a cell of another kind when a changed stimulus is applied."

In some cases a portion of the stroma seems to grow into the edges of the tumor from the surrounding tissue and the subject is so interesting that further studies will be made.

The tumor development is not due to diminished external resistance but to an increased internal stimulus central within certain infected cells. That this stimulus can act at a distance—i. e., is not confined strictly to the infected cells—seems probable both from the macroscopic appearance of stems penetrated by the tumor strand and from the findings in the sections made from the material treated with gold chloride. The reader is referred especially to the wood overgrowths shown on Plates XXV, LXII (Figure A), and LXIII. Here the tumor strand containing the bacteria lies in previously formed dormant tissue at the base of the wood wedges next to the pith far away from the cambium which originates new wood. Yet the wood on that side of the stem is enormously overgrown. Since we have no reason to think the cambium infected by the tumor-producing bacteria because it has developed normally and is only different from that on the other side of the stem in having laid down an excessive volume of wood, we can only account for this overgrowth by postulating action at a distance, exerted by the tumor strand. We might assume either a weak toxic action on the cambium exerted by substances diffused from the infected cells of the tumor strand, or only that the growth has been induced by the stimulus of an extra supply of water and other foods drawn into this part of the stem by the presence of the rapidly growing soft tissue of the strand. In that case, however, it is hard to account for the fact that the bark is not involved in this overgrowth. The amount of overgrowth in the wood seems to depend on the size of the tumor strand. Compare in this particular the plates already referred to with Plates LXVII and LXXVIII, in which the tumor strand is small.

Reference has been made (p. 12) to the morphological similarities between this disease and malignant growths in animals. Here some of the physiological resemblances may be mentioned:

(1) The disease is not an abscess, but an abnormal organization process.

(2) The growth is extra-physiological and detrimental to the plant.

(3) The growth tends to return after excision.

(4) It tends to develop in wounds or irritated places.

(5) There are grades of virulence.

(6) The structure of the gall is looser than that of normal tissues, and decay often sets in early, forming open wounds subject to secondary infections.

(7) The nuclei are hyperchromatic and often stain deepest on the edges of the growth, as in cancer.

(8) There occur in excess in the morbid tissues certain cell products (chemical substances) serving to distinguish the anaplastic cells from normal meristematic or embryonic tissues.

(9) In some cases increased resistance has been developed by inoculations.

Adami in his Principles of Pathology (Vol. I, p. 651) defines neoplastic tumors as follows:

"It is this autonomy, this growth independent of function and of either present or future needs of the organism in which they occur and from which they gain their nourishment, independent also of obvious stimulation from without, that distinguishes the neoplasms proper from all other forms of tissue growth."

From the same source (p. 652) several other pertinent definitions may be quoted. Wishing to include teratomas, he says:

"We prefer C. P. White's statement that 'a tumor proper is a mass of cells, tissues, or organs resembling those normally present, but arranged atypically. It grows at the expense of the organism without at the same time subserving any useful function.' Von Rindfleisch characterizes them as a 'localized degenerative excess of growth'; i. e., the very excess of growth is regarded as in itself a degeneration; Birch-Hirschfeld, as originating spontaneously, becoming separate from the physiological tissues in their physiological and functional relationships, as developing from the cells of the body, and possessing progressive growth; Ribbert, as 'self-confined, dependent upon the organism for their nourishment, but otherwise largely if not quite independent, corresponding more or less but never absolutely with the tissues of the natural body, and presenting no definite limit, to their growth.' Lubarsch's definition is closely allied: 'Under tumor proper we have to understand those growths of apparently independent origin which histologically correspond in structure more or

less completely with the matrix from which they originate, but in form are atypical; which further, in spite of their organic connection with that matrix, and in subjection apparently to laws of their own, pursue an independent existence which is not, or only exceptionally, of advantage to the organism as a whole.'"

Excluding the hypotheses, these definitions apply strictly to the growths here described. Indeed, in terms of morphology and physiology, excluding teratomas, it would be difficult to frame a definition of tumors as a whole which would exclude crown galls. The only way they can be excluded is to say that they occur on plants and are of known origin, whereas the others occur on animals and are of unknown origin, and that would be begging the question.

## RÉSUMÉ.

The principal facts brought to light during this study and our earlier studies may be summarized as follows:

(1) Crown galls occur on a great variety of plants, but not always on the crown; any part of the root or shoot is liable to attack.

(2) They are injurious to the plant in varying degrees, depending on the species, on the parts attacked, on the size and vigor of the individual, etc. They are most injurious to young and rapidly growing plants.

(3) Young, well-nourished, rapidly-growing tissues take the disease more readily than old or slow-growing ones.

(4) They are all of parasitic origin, unless the one on the beet studied by Jensen, Reinelt, and Spisar, in Europe, should prove an exception. We found it difficult to obtain virulent cultures from old galls occurring naturally on the sugar beet, but did finally obtain slow-growing tumors from certain colonies (Bul. 213, Pl. XXXVI).

(5) The structure of crown gall is unlike that of club-root of cabbage, which is a hypertrophy rather than a hyperplasia.

(6) We have isolated the parasite from 24 species belonging to 14 families of phanerogams. Some species have resisted infection.

(7) These galls are due to schizomycetes, either to one polymorphic species, or to several closely related species. Further studies are necessary. For notes on the morphology and biology of these isolations see Bulletin 213, page 127.

(8) The infectious nature of the organism isolated has been proved by hundreds of inoculations and its ability to produce galls on other plants than the one from which it was isolated by many cross inoculations. (Bul. 213, p. 133.)

(9) The parasite has been shown to occur not only in the primary tumor, but also in the secondary tumors and in the connecting tumor strand. Once only in the latter.

(10) Various noninfectious saprophytes also occur in crown galls especially when old, viz, white, green-fluorescent, yellow, and pink bacteria; fungi; mites; myxomycetes, etc. Other infectious organisms may also gain an entrance, viz, the pear-blight bacillus, the fungi of root rot, and borers which, especially in the peach, seem to prefer the soft tissues of the galls.

(11) The parasite has been grown in pure culture on a variety of media and its morphology and cultural peculiarities determined.

(12) When taken from young agar or bouillon cultures, *Bact. tumefaciens* is a short rod with rounded ends, dividing by fission and motile by means of a polar flagellum (sometimes 2 or 3 are present). Short chains and filaments occur. Under unfavorable conditions branched forms (involution bodies) are common. It stains readily, but not by Gram. It is not acid-fast. It is not distinctly capsulate and does not produce spores. For additional details see Bulletin 213.

(13) It grows readily on a variety of the common culture-media, but nearly always it is slow to start off when cultivated directly from the tumors. It forms small, white, wet-glistening, circular, flat colonies on agar plates and is also white on other media. It does not liquefy gelatin nor are its gelatin colonies characteristic. The organism is aerobic in its tendencies. It forms stringy filamentous growths in bouillon. The coagulation of milk is delayed. It blues litmus milk. It does not reduce nitrates nor grow well in Cohn's solution (daisy). It is sensitive to heat, to dry air, to acids, and to germicides. For additional notes see Bulletin 213.

(14) The organism slowly loses virulence when grown on culture-media. We believe that many of the bacteria also lose virulence within the tumor, because not all colonies growing typically on agar poured plates, and in other media, are infectious.

(15) Some of its biochemical properties are now known, to wit, the production from grape sugar of an acid which seems to play an important rôle in the tumor development. Alcohol also occurs.

(16) It has also been stained within the tissues of the tumor and its form and locus therein determined.

(17) The morphology and biological peculiarities of the tumor growth have been studied.

(18) The tissues of the gall multiply excessively and in opposition to the best interests of the plant.

(19) The galled tissue, which is often of a soft, fleshy nature, is much subject to decay. It is not usually corked over, and this absence of a protective surface allows the ready entrance of water and of other parasites.

(20) The tumor originates in meristem, usually in the cambium region. It may perish within a few months or continue to grow (parts of it) for years.

(21) The tumor consists, or may consist, not only of parenchyma cells but also of vessels and fibers, i. e., it is provided with a stroma which develops gradually as the tumor grows. A proliferating tumor usually contains not only meristem but pitted vessels and sieve tubes; it may also contain wood fibers, but does not always.

(22) The tumor sends out roots (tumor strands) into the normal tissues. These may extend for some distance from the tumor—how far is not known. These strands consist of meristem capable of originating medullary rays, tracheids, and sieve tubes. In the daisy the strand passes through the protoxylem region of the stem. It is rich in chloroplasts. It usually takes a deeper stain than the surrounding tissues, from which it is sharply delimited. A considerable part of it consists of unripe, actively vegetating cells.

(23) In the daisy the infiltrations are not through the vessels, but between them in a tissue offering little resistance to intrusion, i. e., the region occupied by the thin-walled, delicate spiral vessels.

(24) In the substance of these deep-lying strands secondary tumors develop. These gradually rupture their way to the surface.

(25) The secondary tumors tend to take on the structure of the primary tumor, e. g., if the latter is in the stem and the former in a leaf, the secondary tumor shows a stem structure.

(26) The stimulus to tumor development comes from the presence of the parasite within certain of the cells. Apparently it is not in all. The organism has not been observed with certainty outside of the cells, either in the vessels or the intercellular spaces, nor is it abundant in the cells. Usually copious inoculations have to be made to insure cultures.

(27) Under the microscope it can not be made out in unstained sections with any certainty, and most bacterial stains also fail to differentiate it in the tissues. (Histological Pls. VII to CIII.) It is best observed in tissues impregnated with chloride of gold. (Pls. CV to CVII.)

(28) When subjected to unfavorable conditions in cultures the parasite develops involution forms consisting of club-shaped, Y-shaped, and variously branched bodies. The same bodies occur within the cells of the tumor, making it reasonable to infer that the parasite is there exposed to similar unfavorable conditions.

(29) These involution forms may be produced at will by the addition of dilute acid to young cultures. The abnormal forms (Y's, etc.) thus produced either refuse to grow when sown in agar plates or develop colonies slowly. The same results are obtained very often on making poured plates from the tumors, viz, either no colonies appear or slowly developing ones, but subcultures from these slowly developing colonies grow promptly. Sometimes also from the tumor one gets the organism promptly on agar poured plates (third

day). In the delayed cases the mere change from tumor tissue to culture media is not the cause of the delay.

(30) By repeated inoculations through a series of years we obtained (Bul. 213, p. 177) plants which appeared to be more resistant to the disease than check plants, but by subsequent inoculations on descendants of these plants we obtained numerous well-developed primary and secondary tumors, so that the resistance which we obtained must be regarded either (*a*) as of a fugitive nature, or (*b*) as of a low grade easily overcome by a more virulent strain of the parasite. That the cultures used for these subsequent inoculations came from a more virulent strain may be assumed, we think, both because they were plated from a tumor which appeared on one of our most resistant plants, and because the cultures tried on a great number of plants (including those described in this bulletin) produced primary tumors very quickly and showed an unusually strong tendency to develop secondary tumors.

(31) The relation between the host and the parasite may be regarded as a symbiosis in which the parasite has the advantage.

(32) The bacterium is a soil organism and planters should aim to keep their lands free from it by refusing to plant infected stock.

(33) Nurserymen should plant on uninfected land and carefully avoid heeling good stock into soil which has previously received infected plants. Nurserymen have been largely responsible for the dissemination of this disease.

(34) The organism is a wound parasite. Its entrance is favored by careless grafting (Hedgcock) and by the presence of borers, nematodes, etc.

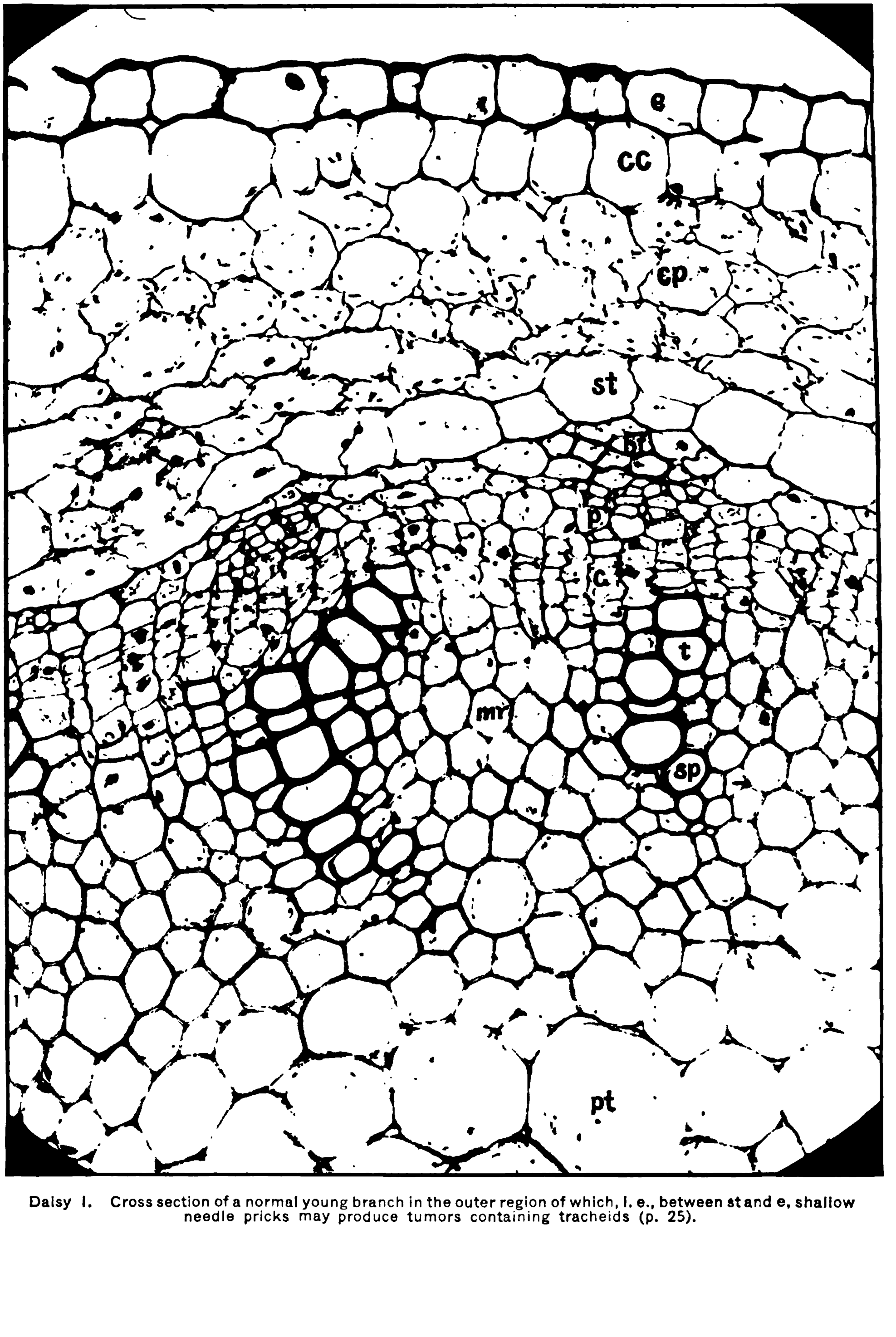
(35) These galls occur on the roots of Legumes and have been mistaken for the nitrogen root nodules.

(36) The development of this disease is regarded as closely paralleling what takes place in cancer of men and animals.

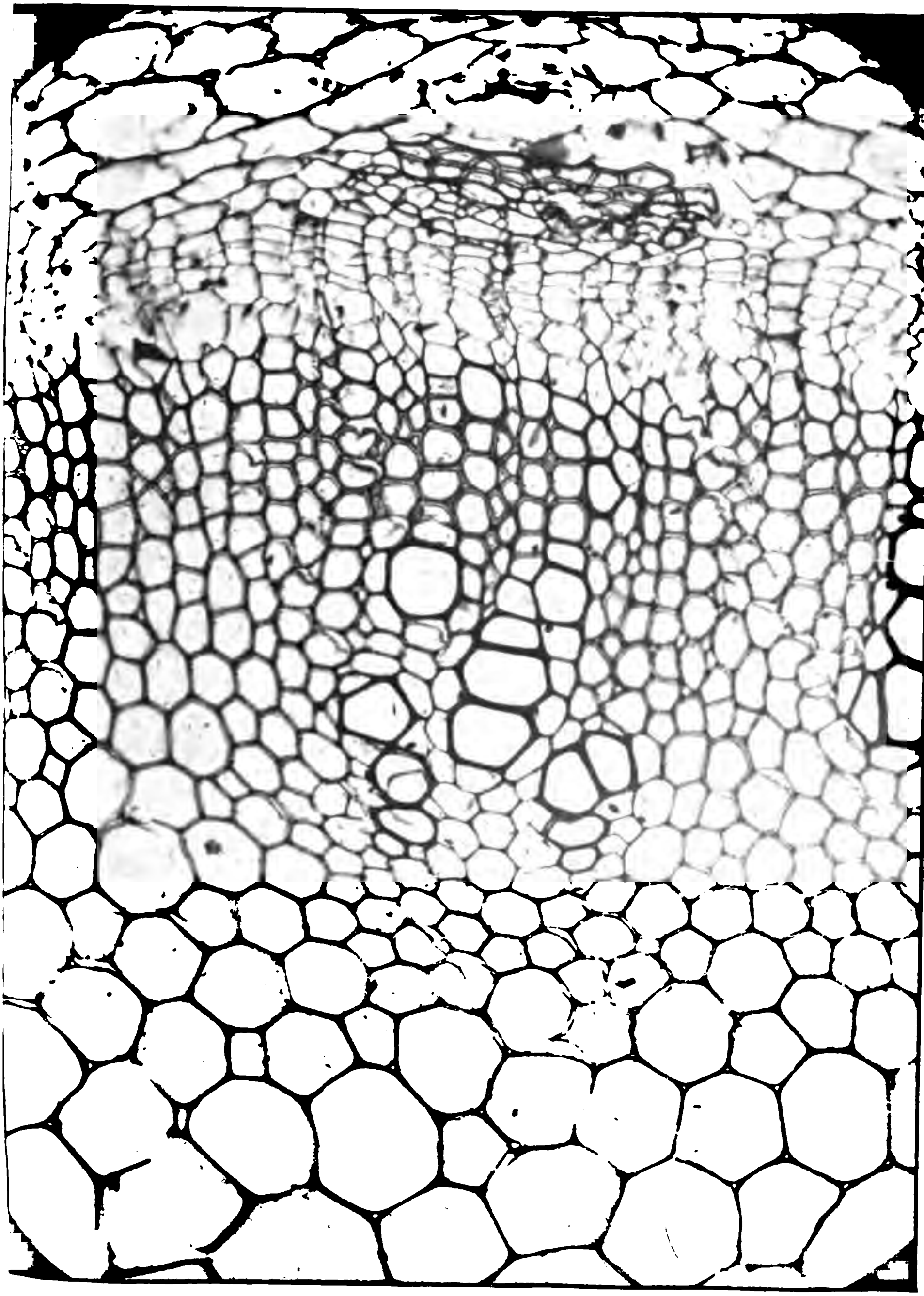
(37) There are no true metastases in crown gall, but this does not, to our mind, militate against the comparison, for whether a cancer shall be propagated by floating islands of tissue, or only by tumor-strands, appears to be a secondary matter depending on the character of the host tissues rather than on the nature of the disease. The essential element is the internal stimulus to cell division.

(38) Nothing in this bulletin should be construed as indicating that we think the organism causing crown galls is able also to cause human cancer, but only that we believe the latter due to a cell parasite of some sort, and offer the preceding pages in support of this contention.

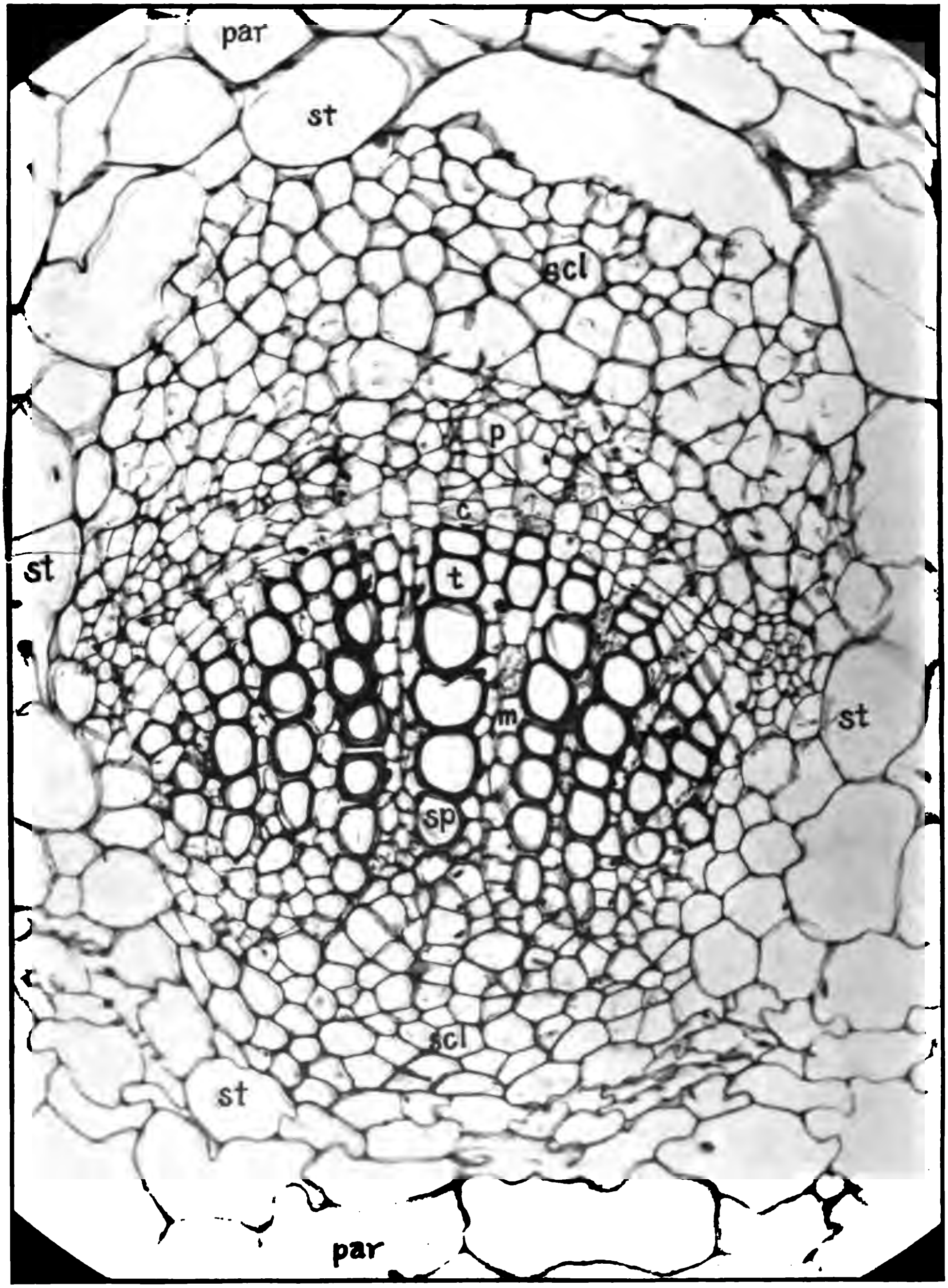
# PLATES.



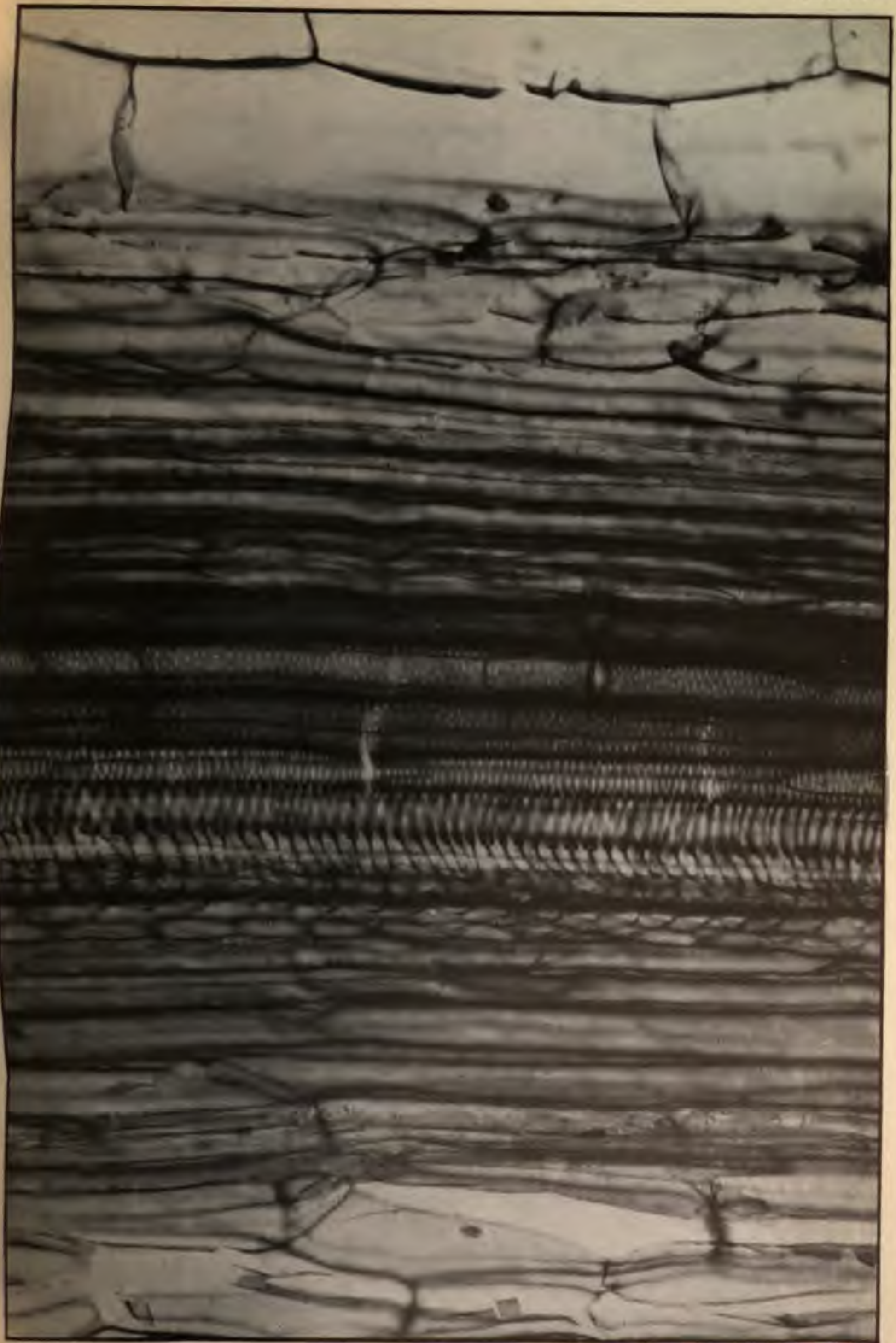

Daisy I. Cross section of a normal young branch in the outer region of which, i. e., between st and e, shallow needle pricks may produce tumors containing tracheids (p. 25).



Daisy I. Cross section of normal branch somewhat older than the preceding (p. 25).

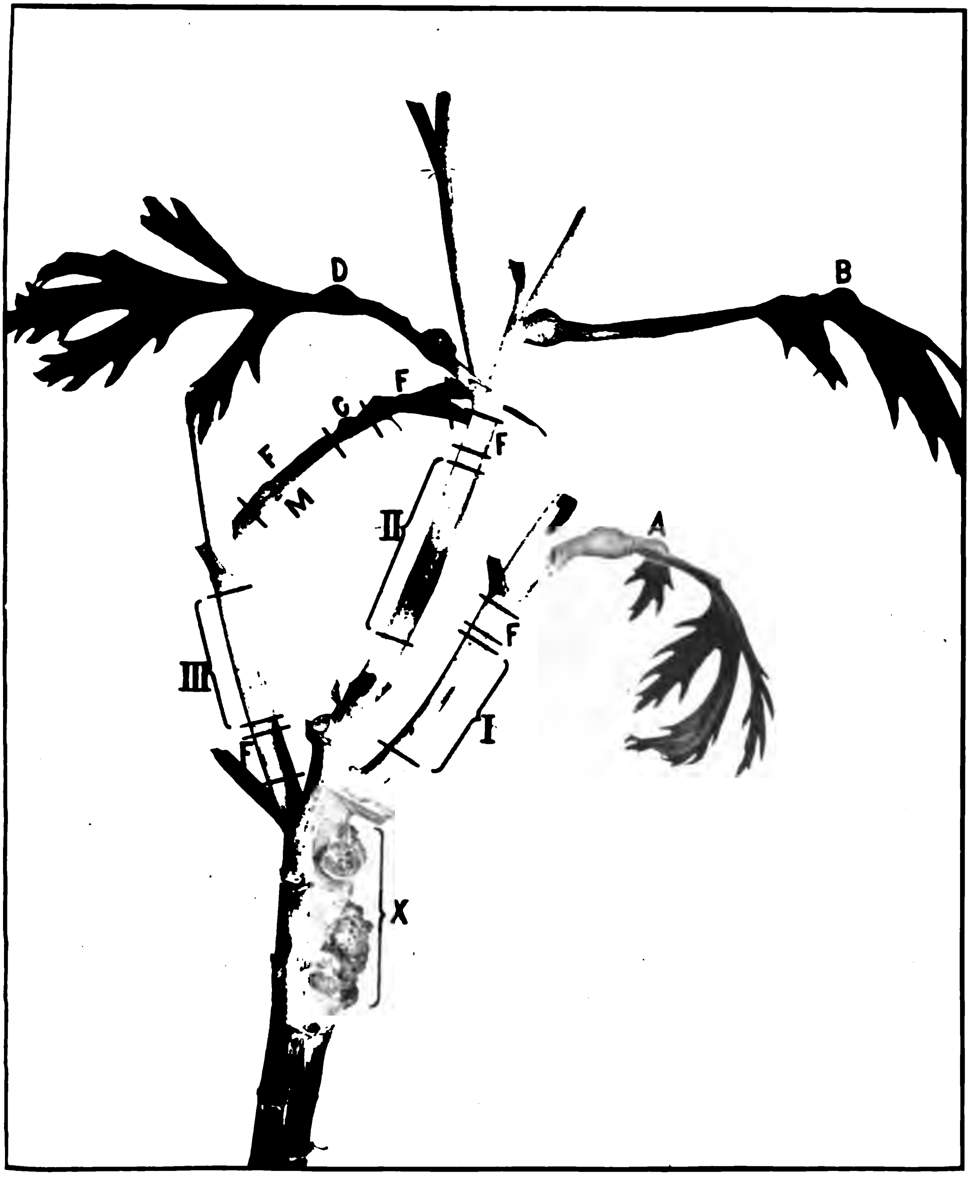



Daisy XIV. Cross section of a normal leaf-trace (p. 26), showing unilateral structure.

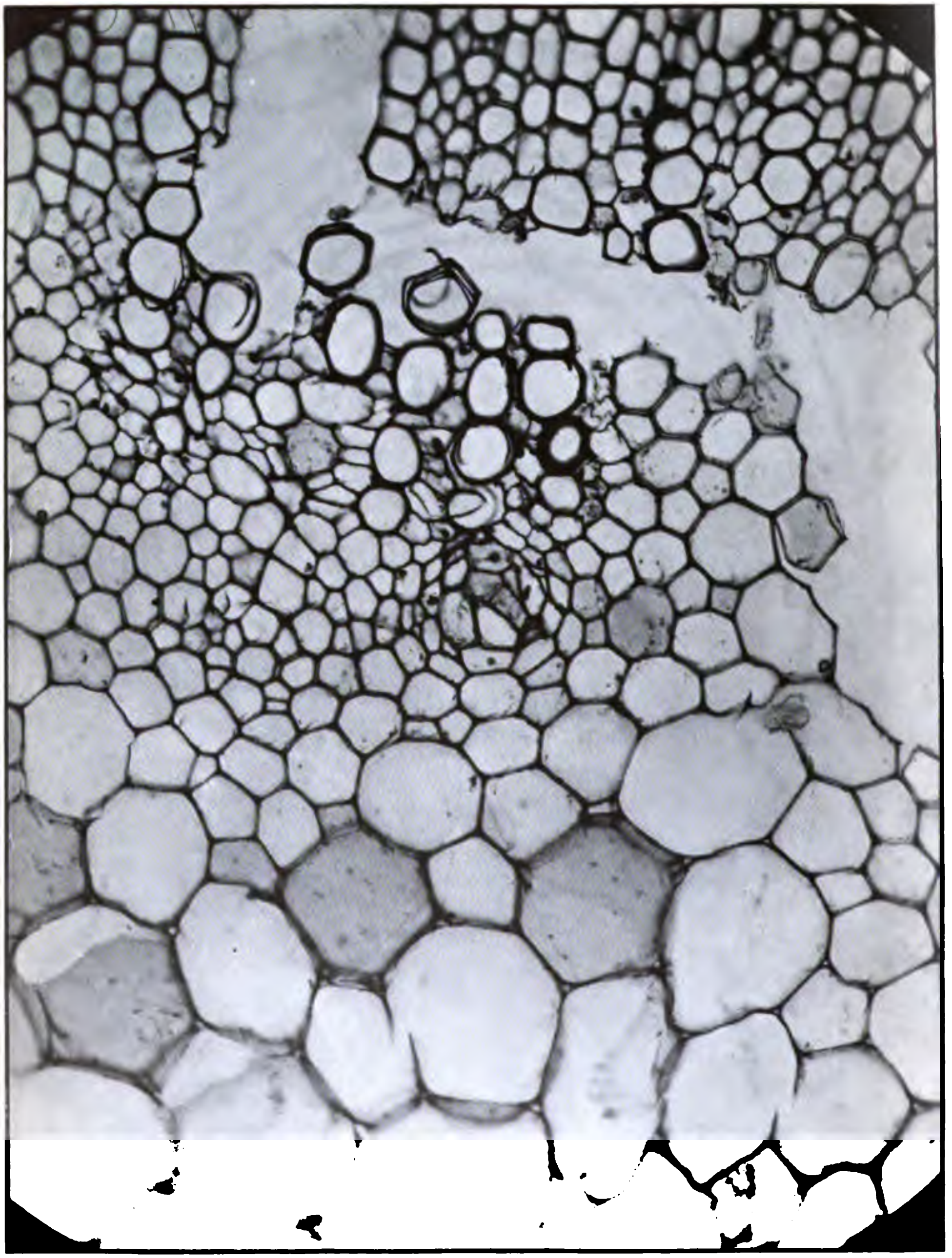


Daisy XXX. Longitudinal section of a normal leaf-trace (p. 26).

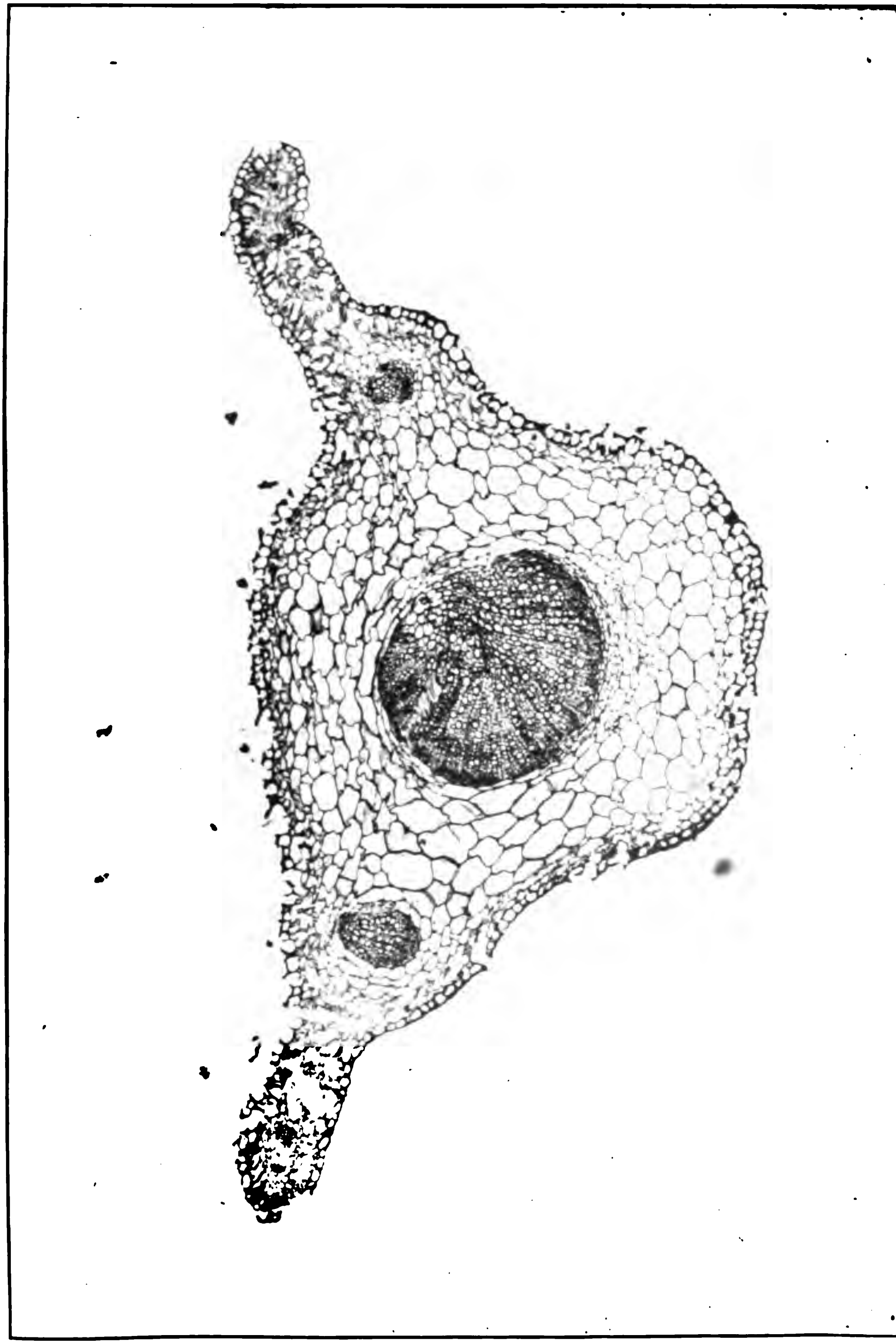
Daisy XXX. Longitudinal section of a normal petiole between leaf-traces (p. 26).



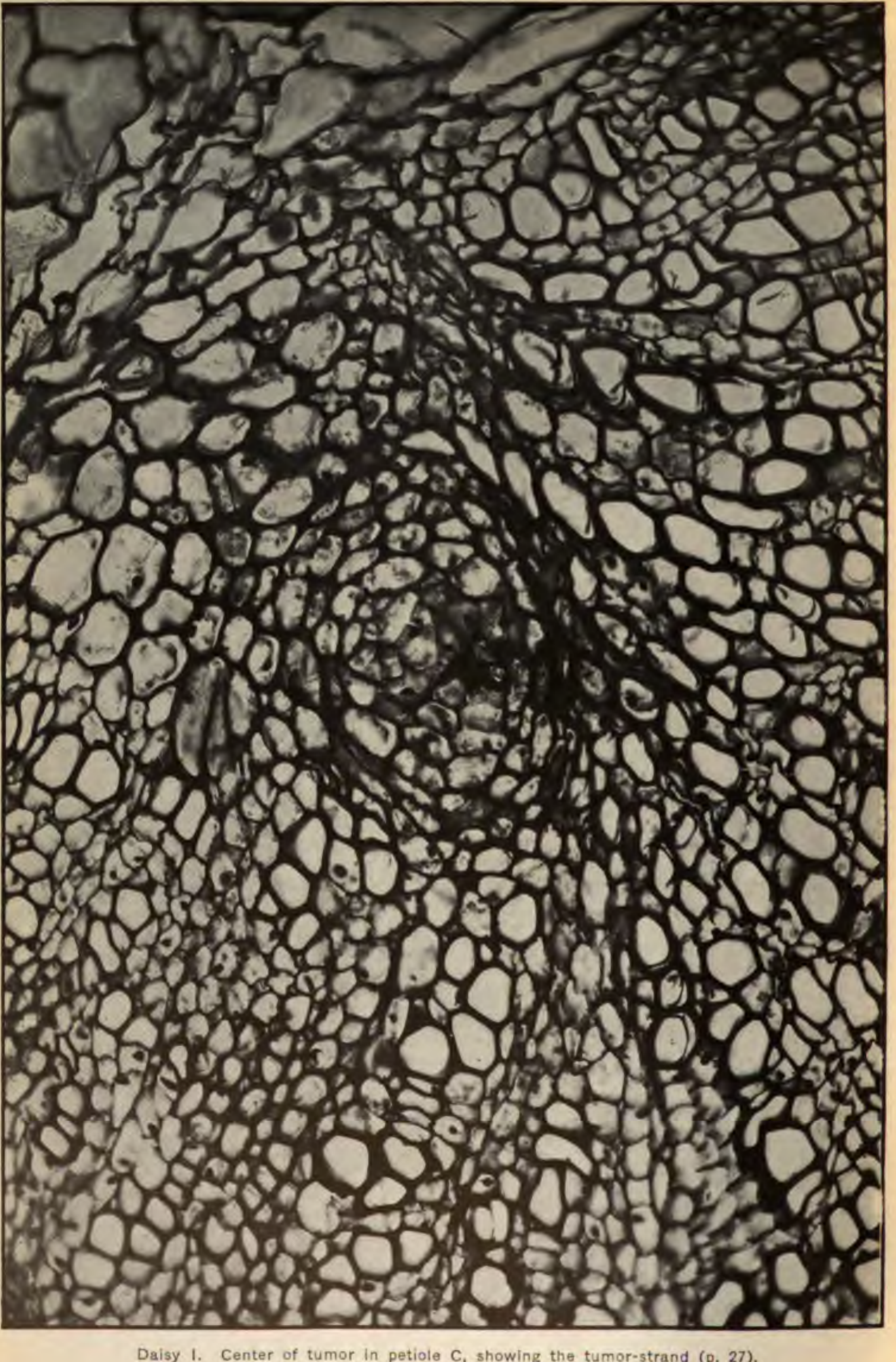

Daisy I. Part of plant showing primary stem tumors (at X) and secondary leaf tumors (p. 26).



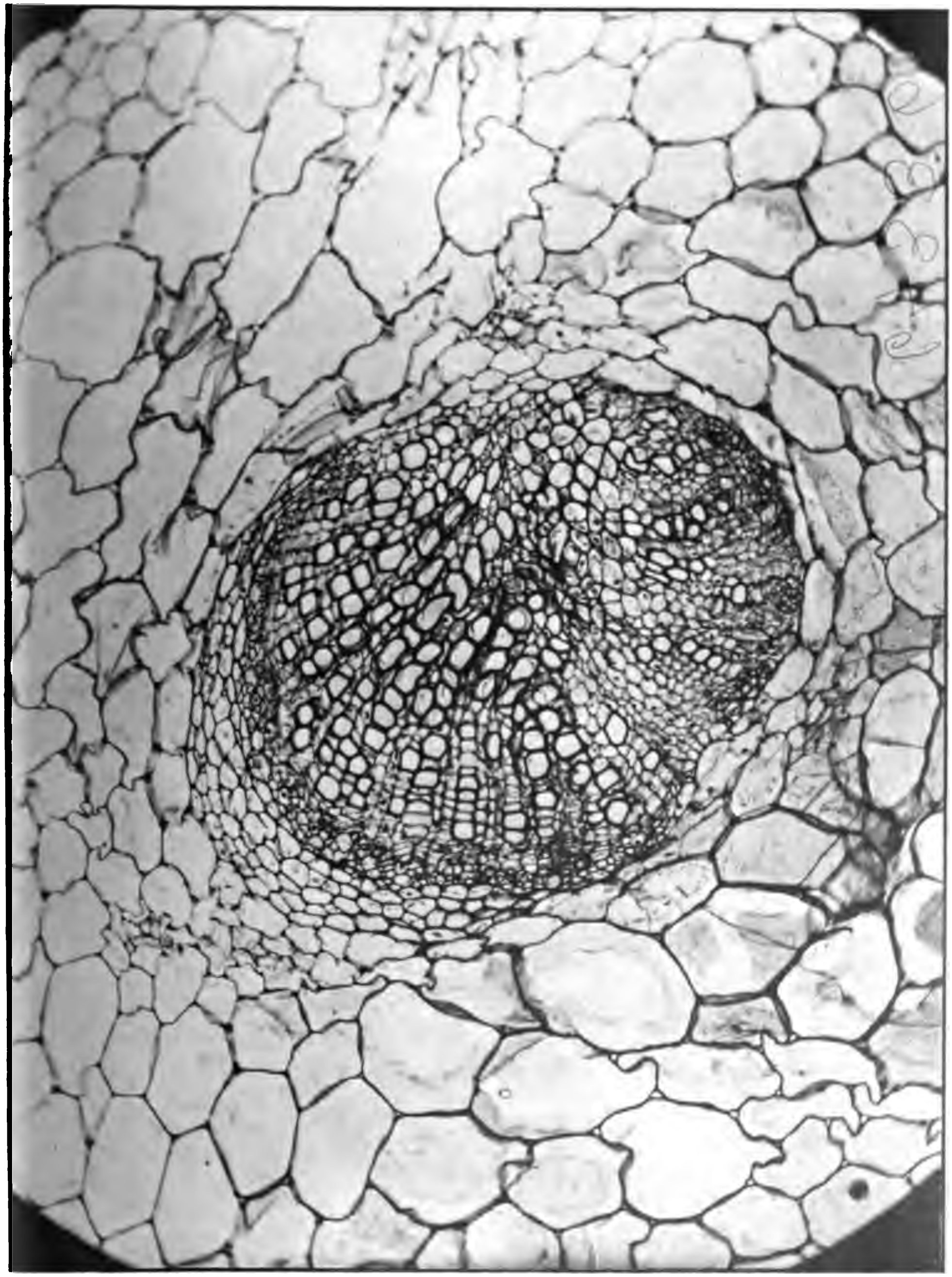
Daisy I. Cross section of Branch III between tumors, showing tumor-strand which passes into petiole C (p. 27).



Daisy I. Cross section of petiole C, central leaf trace diseased (p. 27).

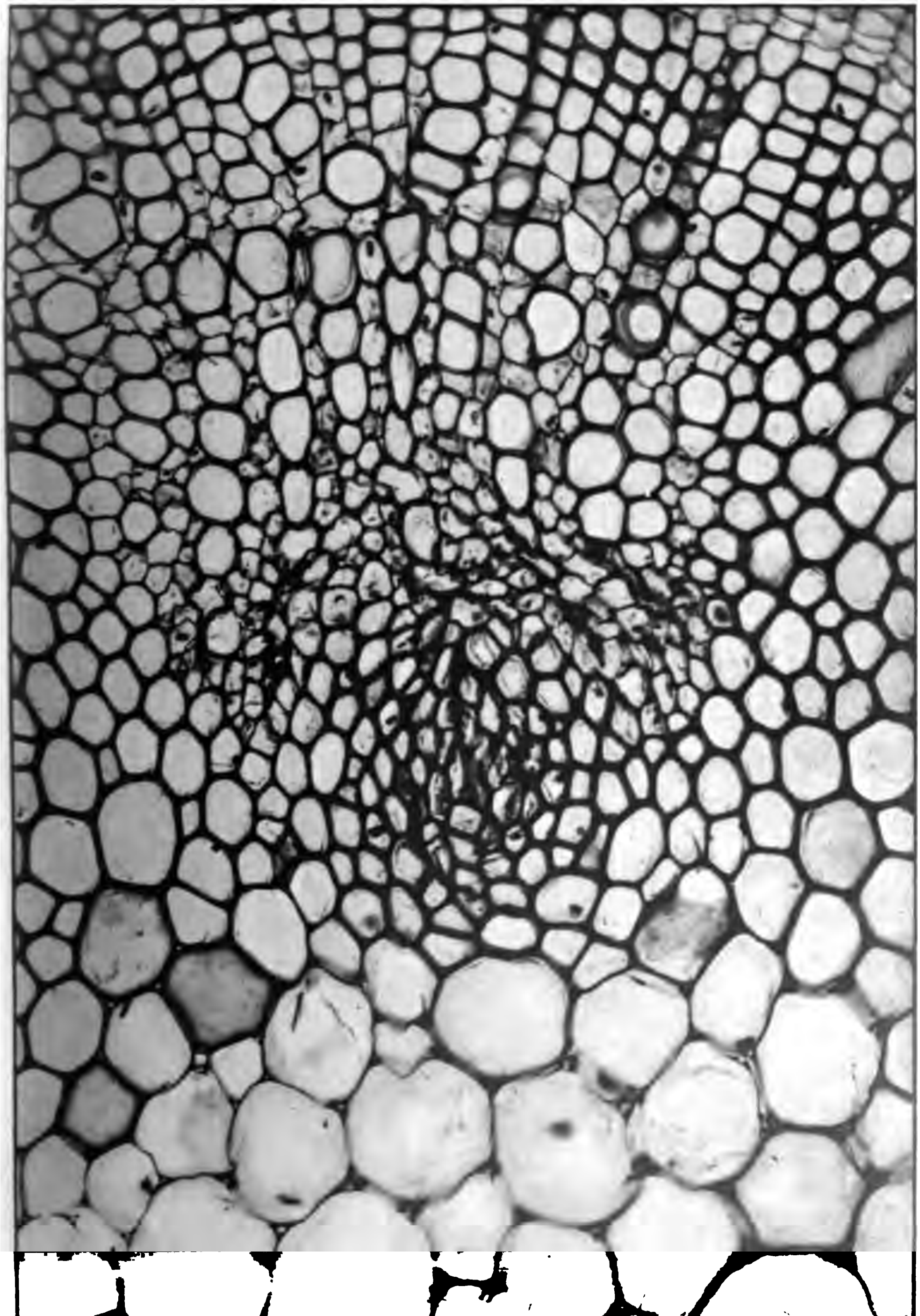


Daisy I. Center of tumor in petiole C, showing the tumor-strand (p. 27).

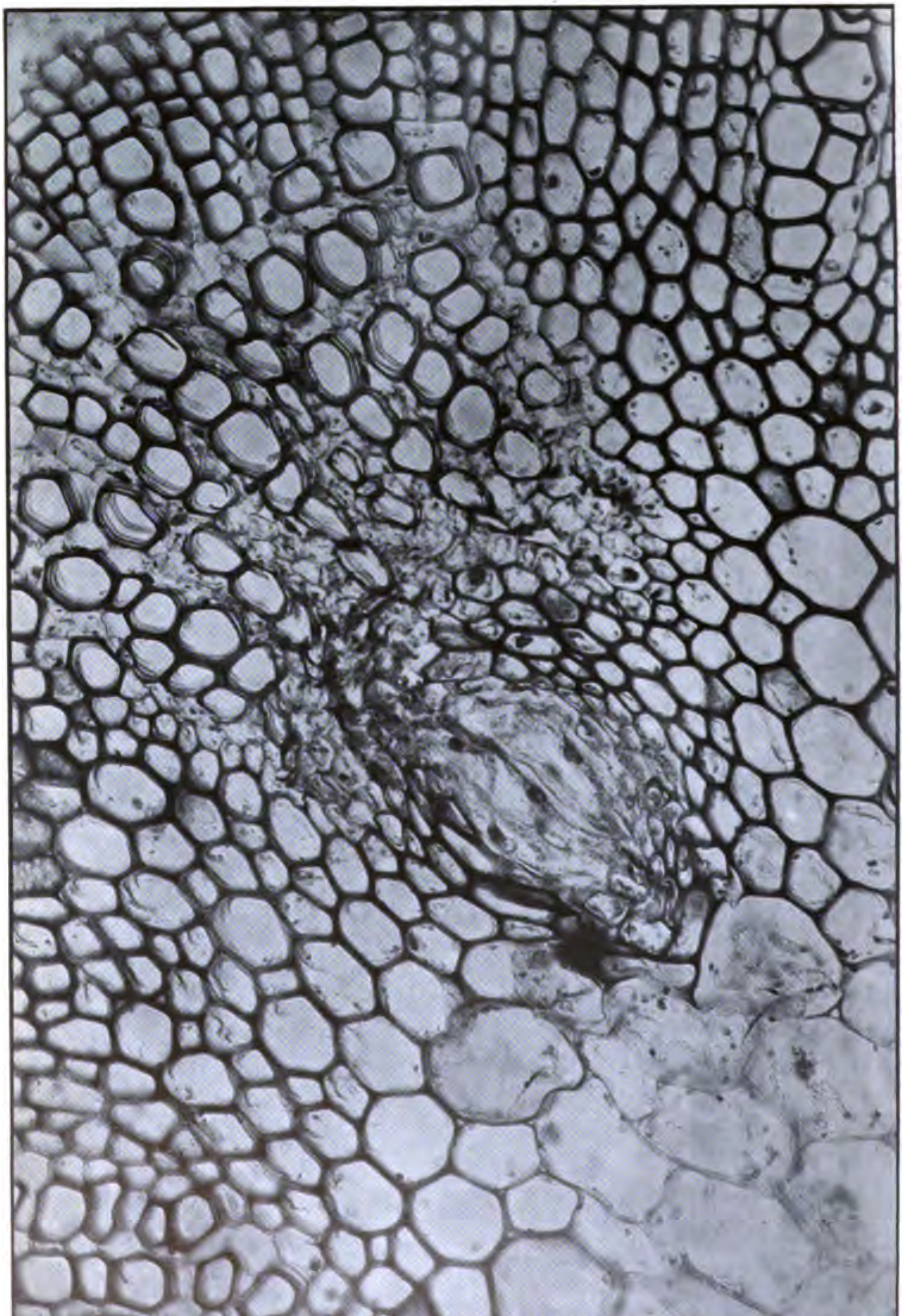


Daisy I. Cross section of petiole C at another level, showing conversion of leaf-trace into a secondary tumor (p. 27).

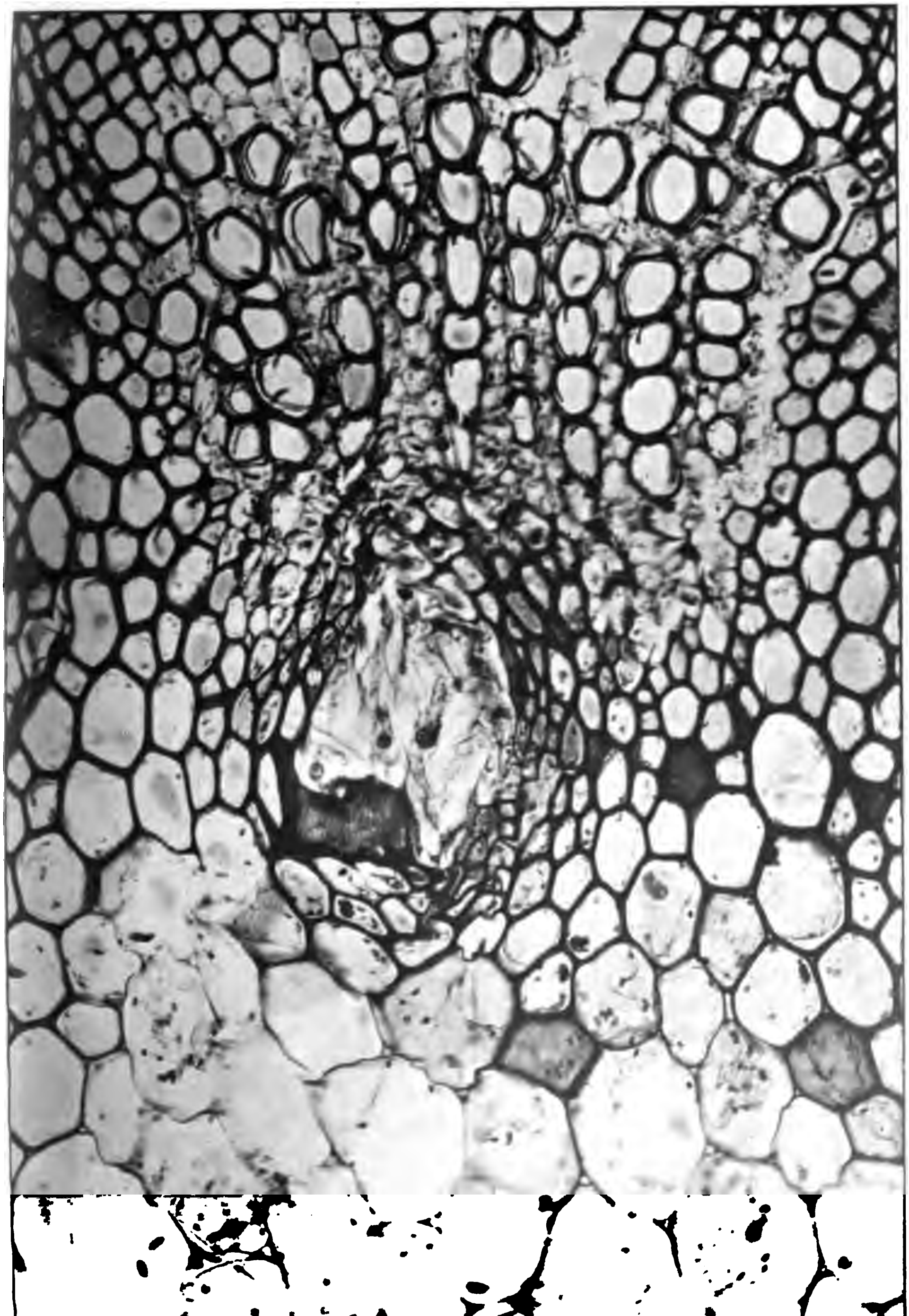
Daisy I. Same as Plate X, but center of tumor, showing strand in its middle portion (p. 27).



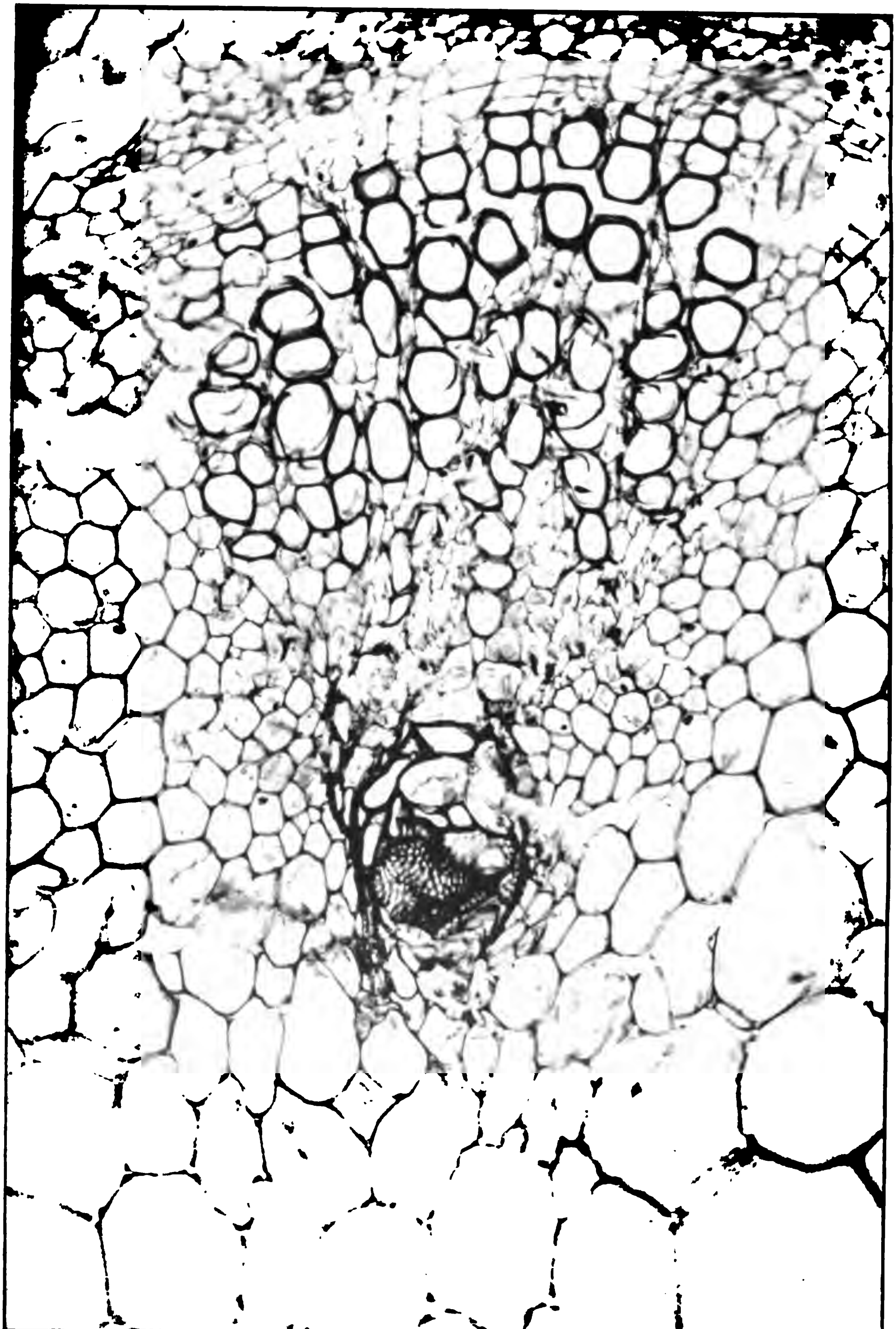
Daisy I. Branch I in cross section between tumors, showing small-celled tumor-strand (p. 28).



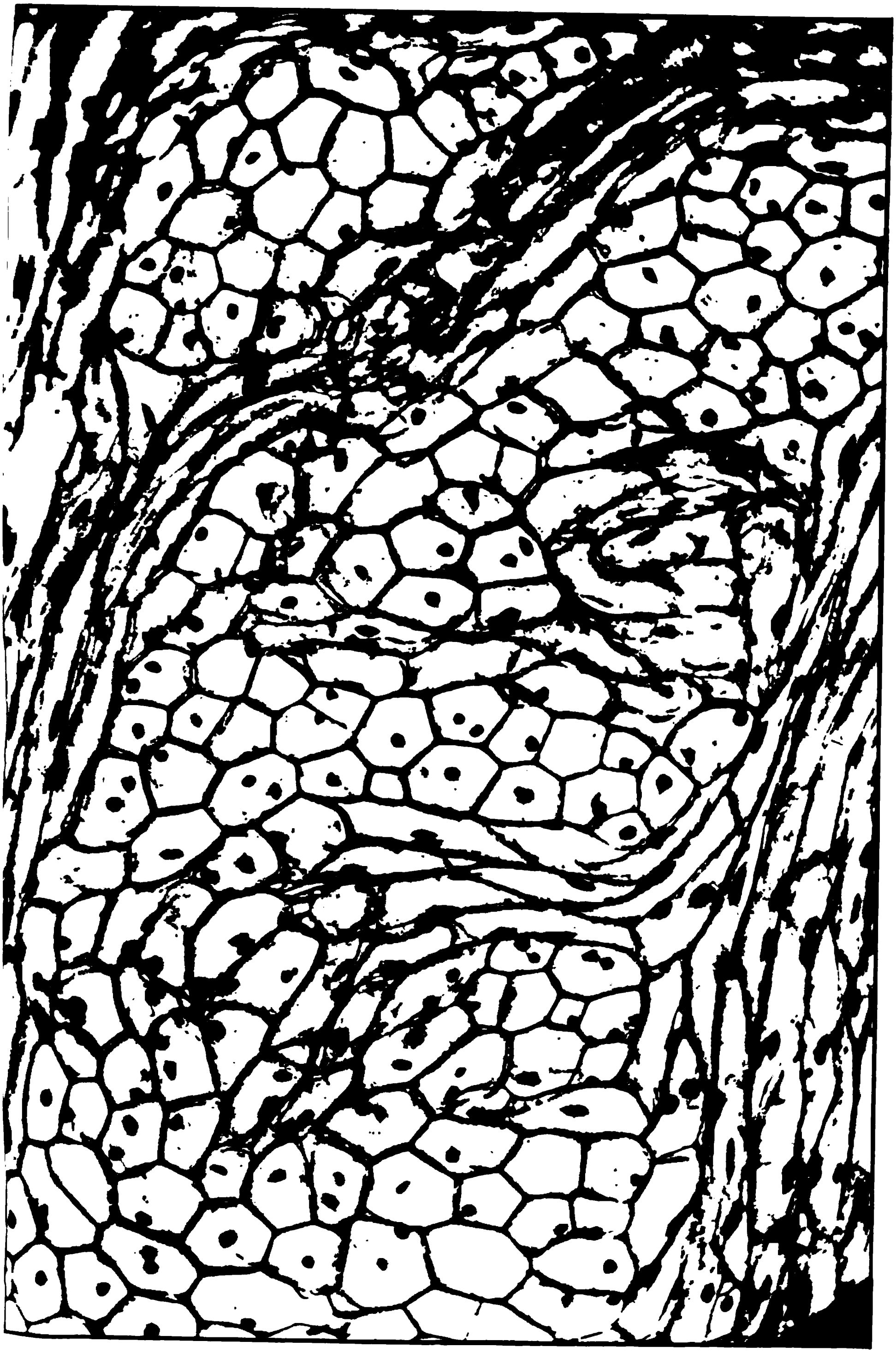
Daisy I. Branch I in cross section at another level, showing large, soft cells in the tumor-strand (p. 28).



Daisy I. Cross section of Branch I, showing tracheids developing in the tumor-strand (p. 28).



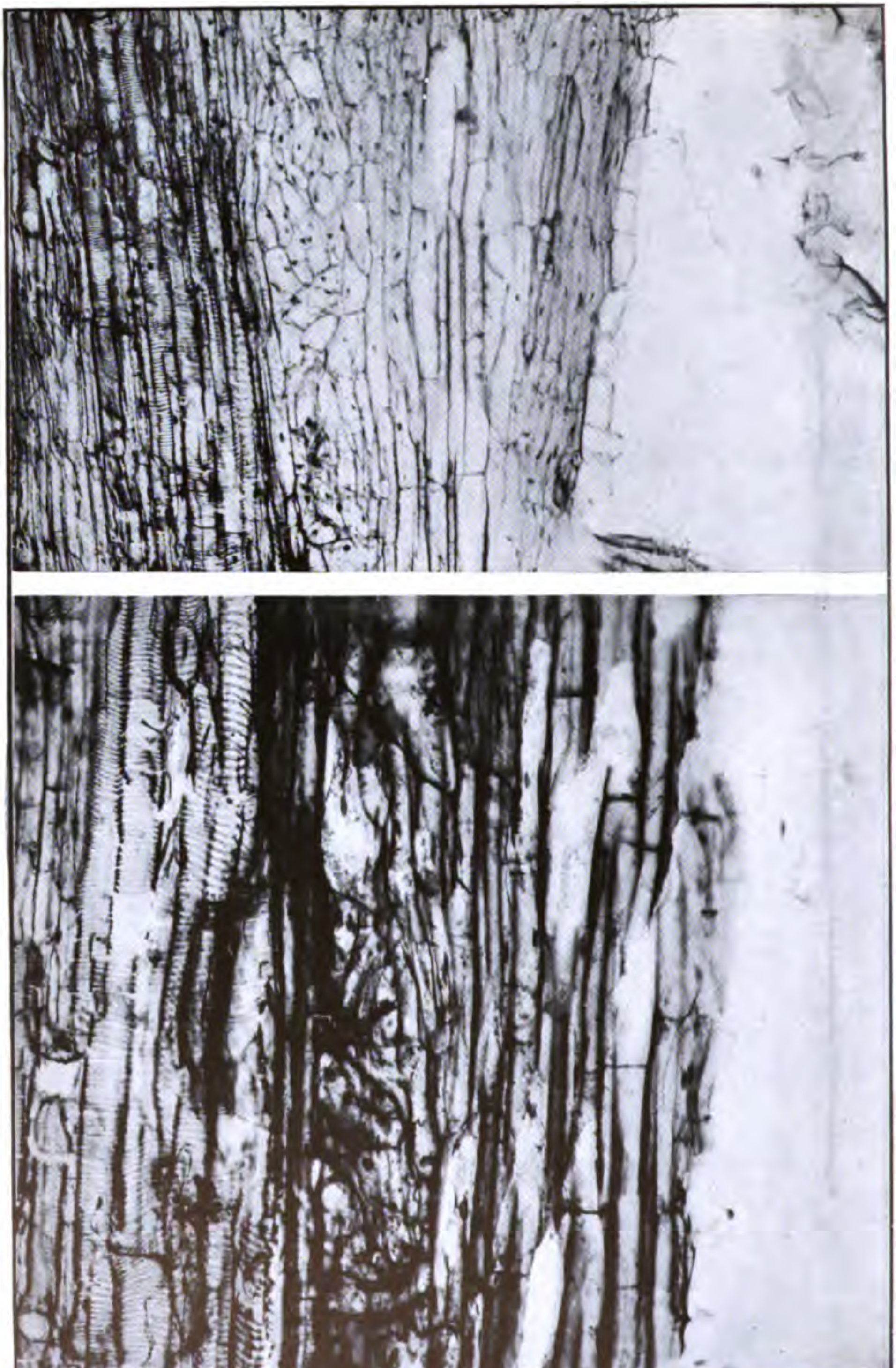
Daisy I. Branch II in cross section between tumors; tracheids in strand (p. 28).



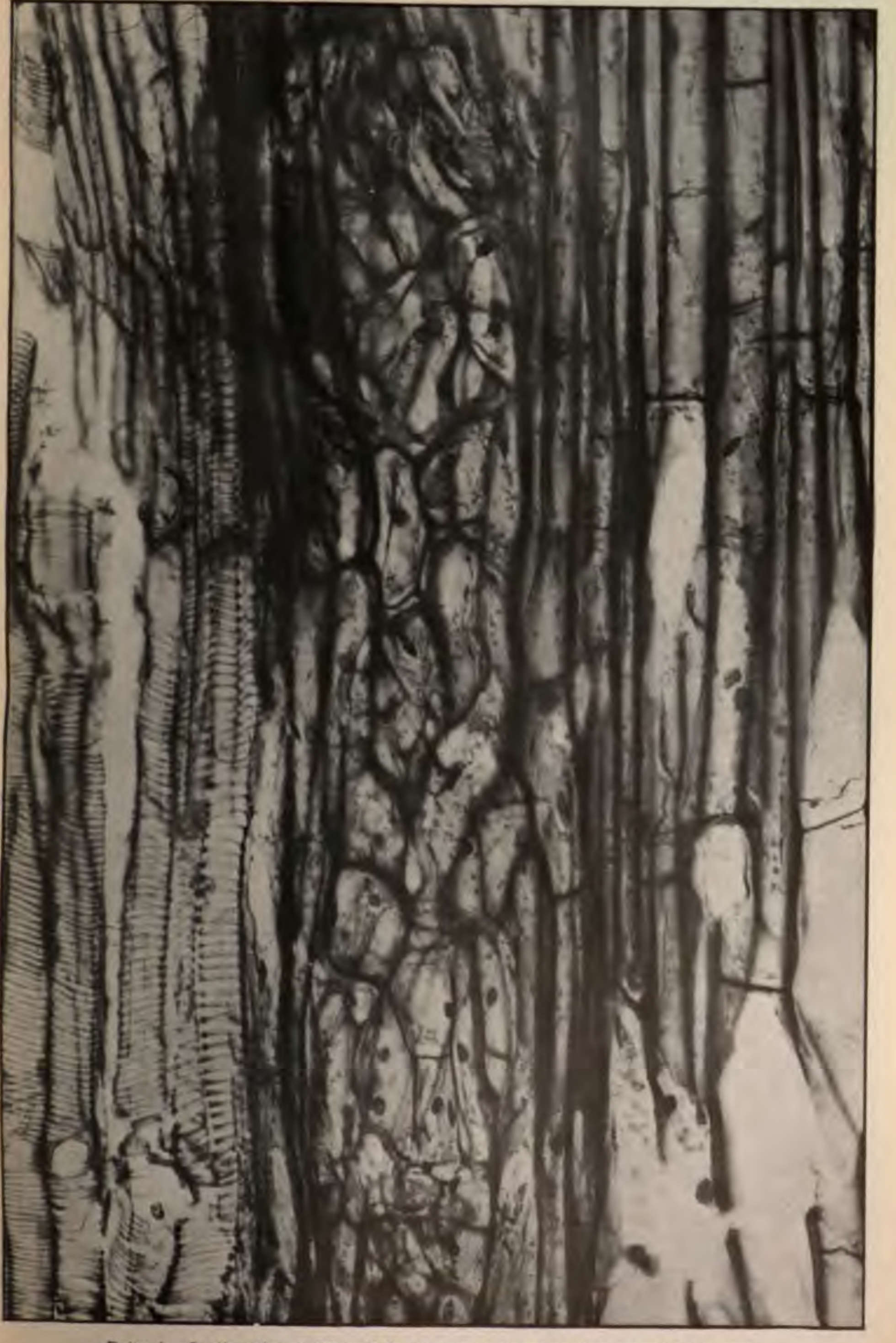
Daisy I. Petiole C. Tumor tissue with bi-nucleate cells (p. 28).


Daisy I. Longitudinal section of petiole C, showing tumor-strand (p. 28).


Daisy I. Continuation of Plate XVII, strand enlarging into a tumor (p. 28).

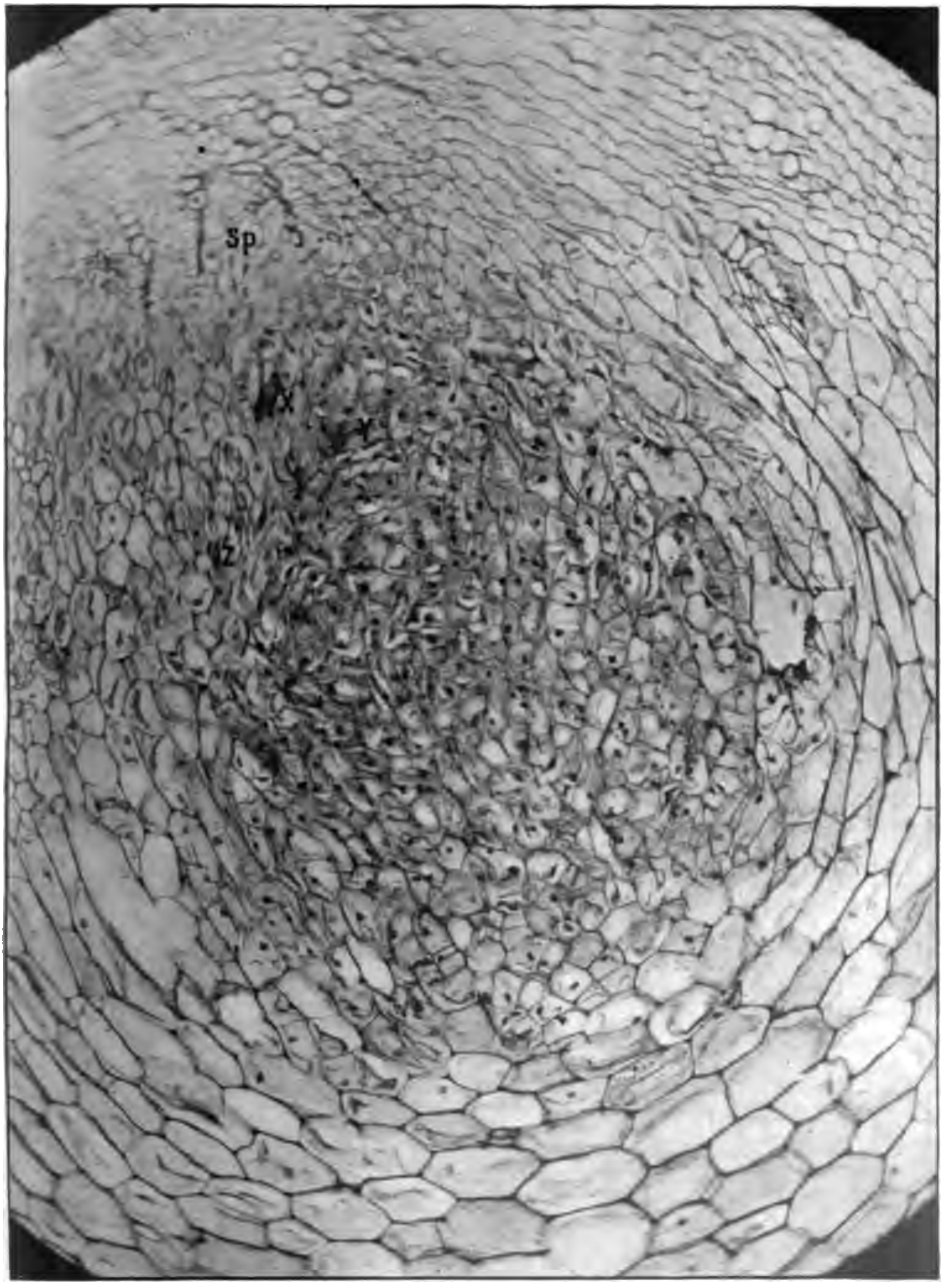


Daisy I. Continuation of Plate XVIII, showing tumor-strand (p. 28).



Daisy I. Continuation of Plate XIX, but tumor-strand further magnified (p. 29).

Daisy II. Cross section of stem between tumors, showing tumor-strand. The wood on that side is slightly enlarged and the pith is compressed. The rest of the stem is normal (p. 29).

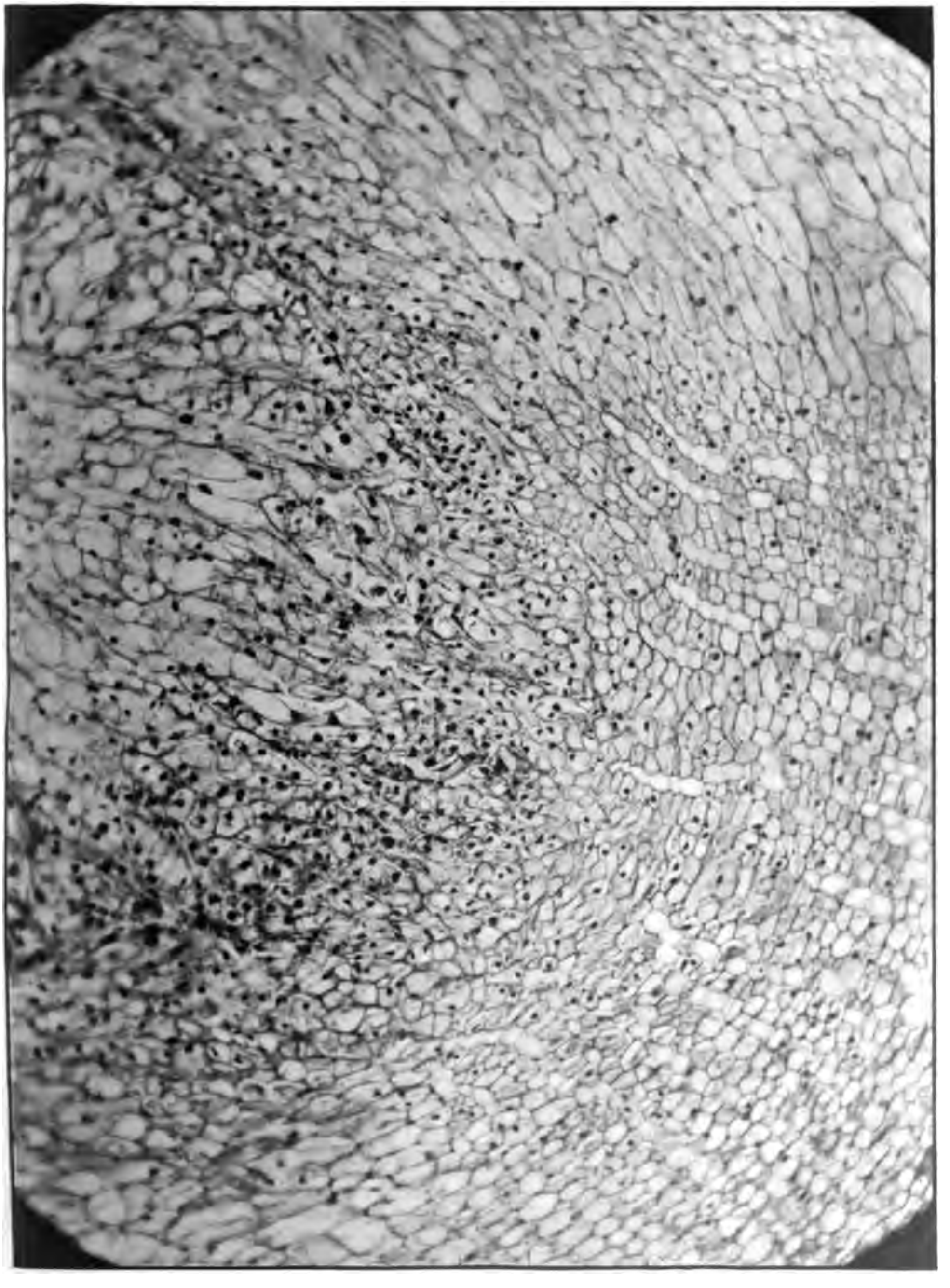



Daisy II. Same as Plate XXI, but tumor-strand further magnified; at the top crushed and displaced spirals (p. 29).


Daisy V. Inoculated plant, showing a primary stem tumor and leaves converted into secondary tumors (p. 29).


Daisy V. Other side of the plant, with sections of the abnormal stem (p. 30).

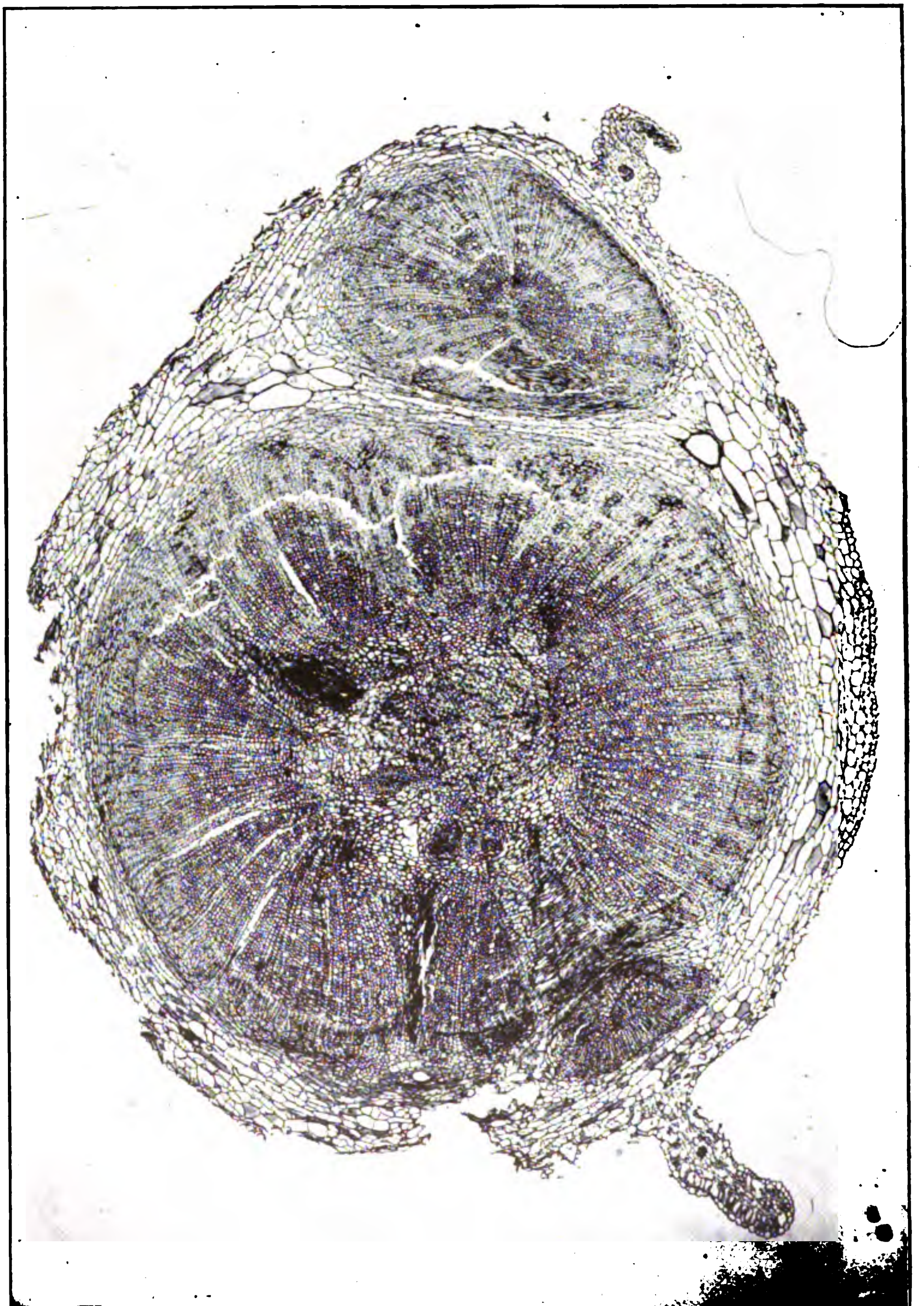
Daisy V. Enlarged cross section of stem between tumors, showing a large tumor-strand with marked enlargement of the wood on that side (p. 30).



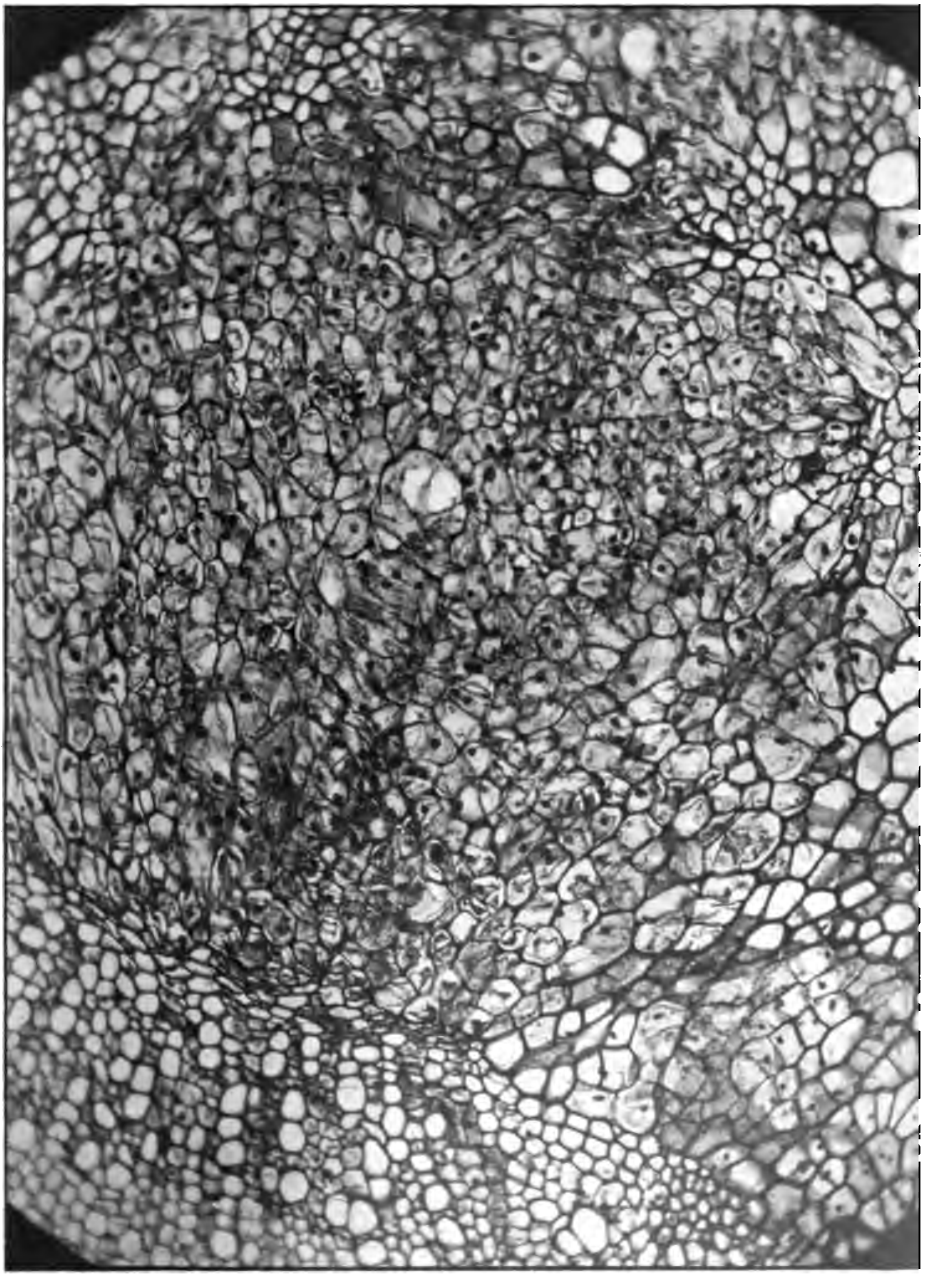
Daisy V. Detail from top of tumor-strand on Plate XXV, showing gradual transition into the wood (p. 30).

Daisy V. Detail from bottom of tumor-strand shown on Plate XXV; flattened pith at left with sharp line of demarcation (p. 30).


Daisy VII. Part of plant, showing primary and secondary tumors (p. 31).

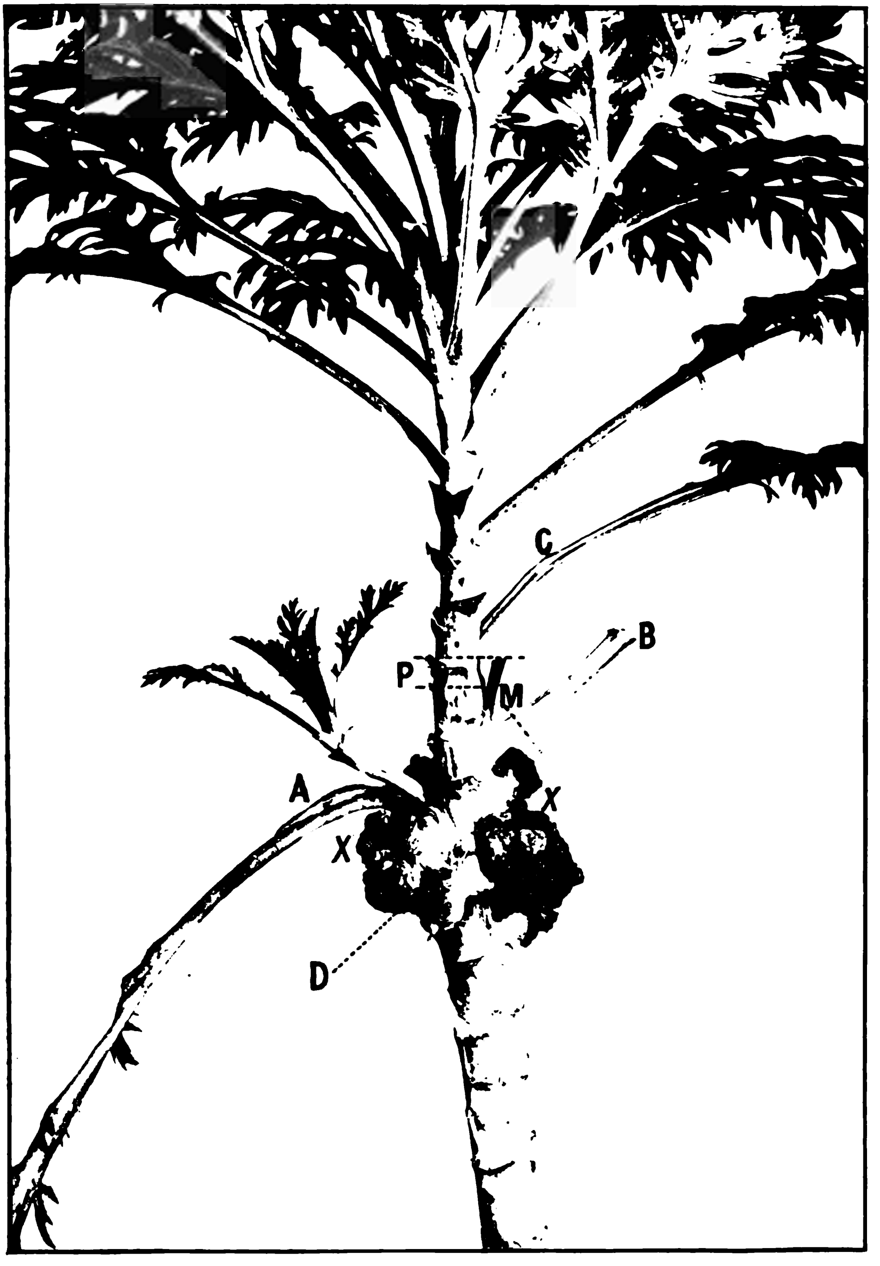


Daisy VII. Cross section of base of petiole A, showing stem structure in three leaf-traces (p. 32).

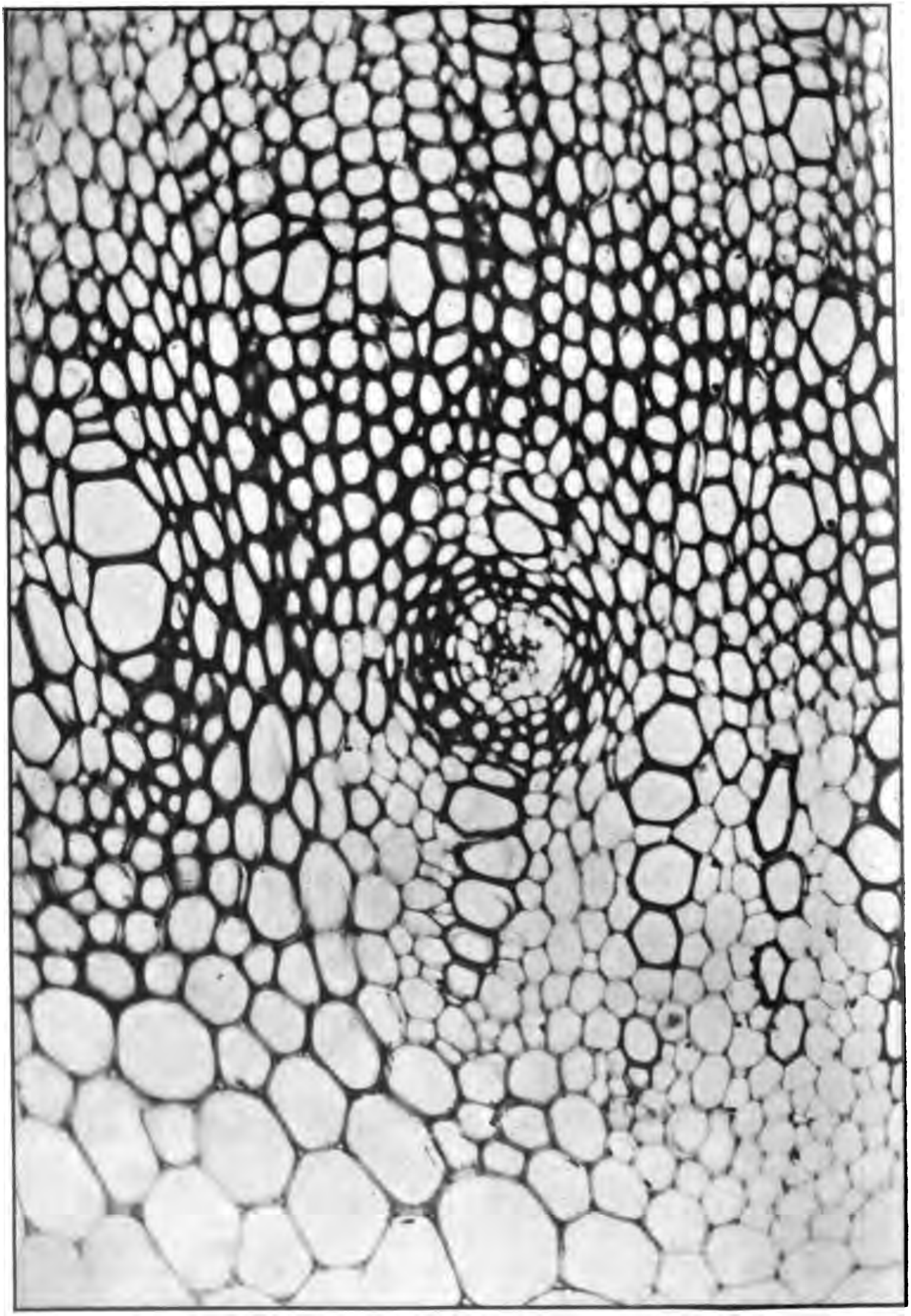


Daisy VII. Cross section of the larger tumor-strand in petiole A; abnormal medullary ray in lower right corner (p. 33).

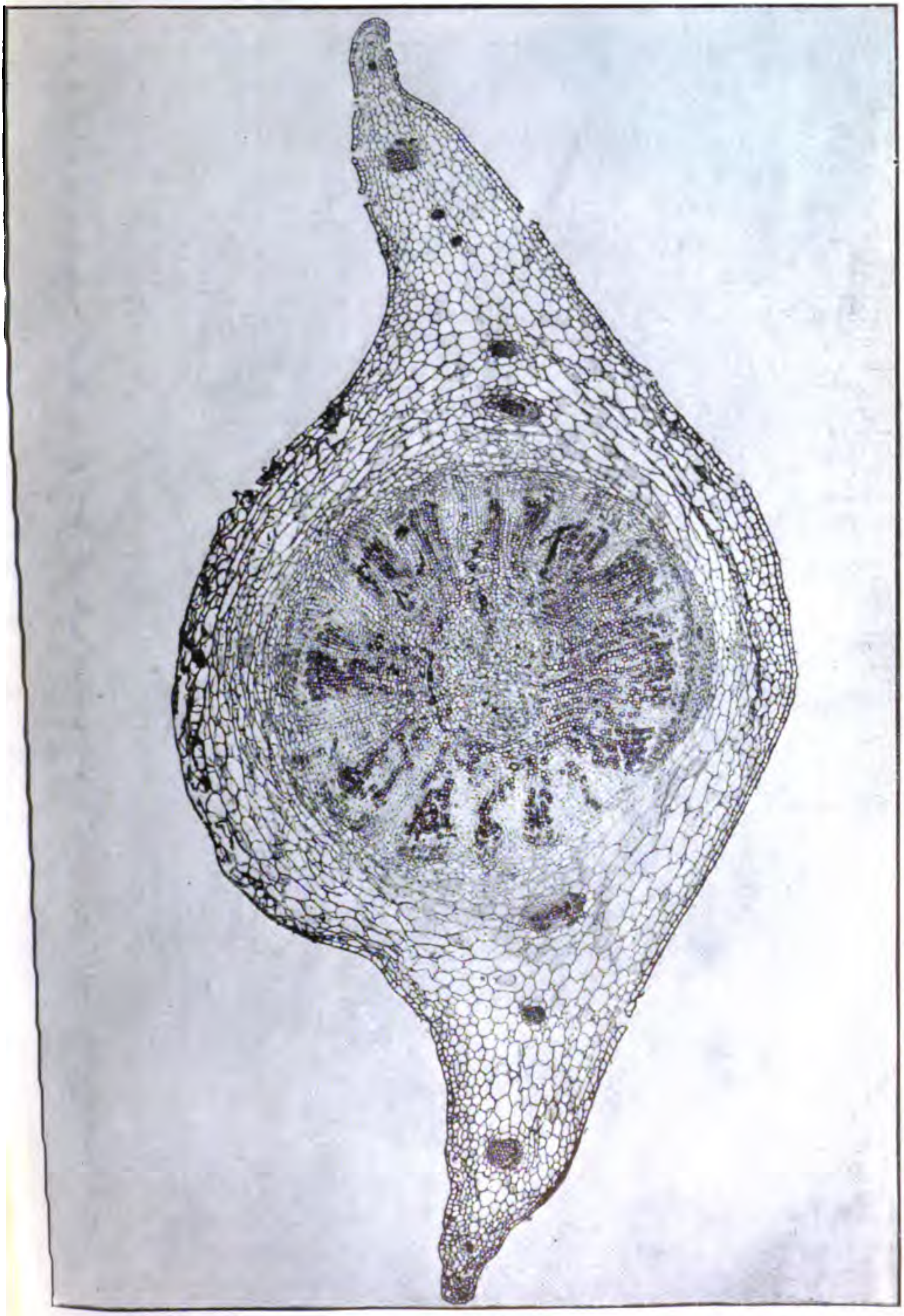
Daisy VII. Cross section of petiole D, showing stem structure (p. 33).



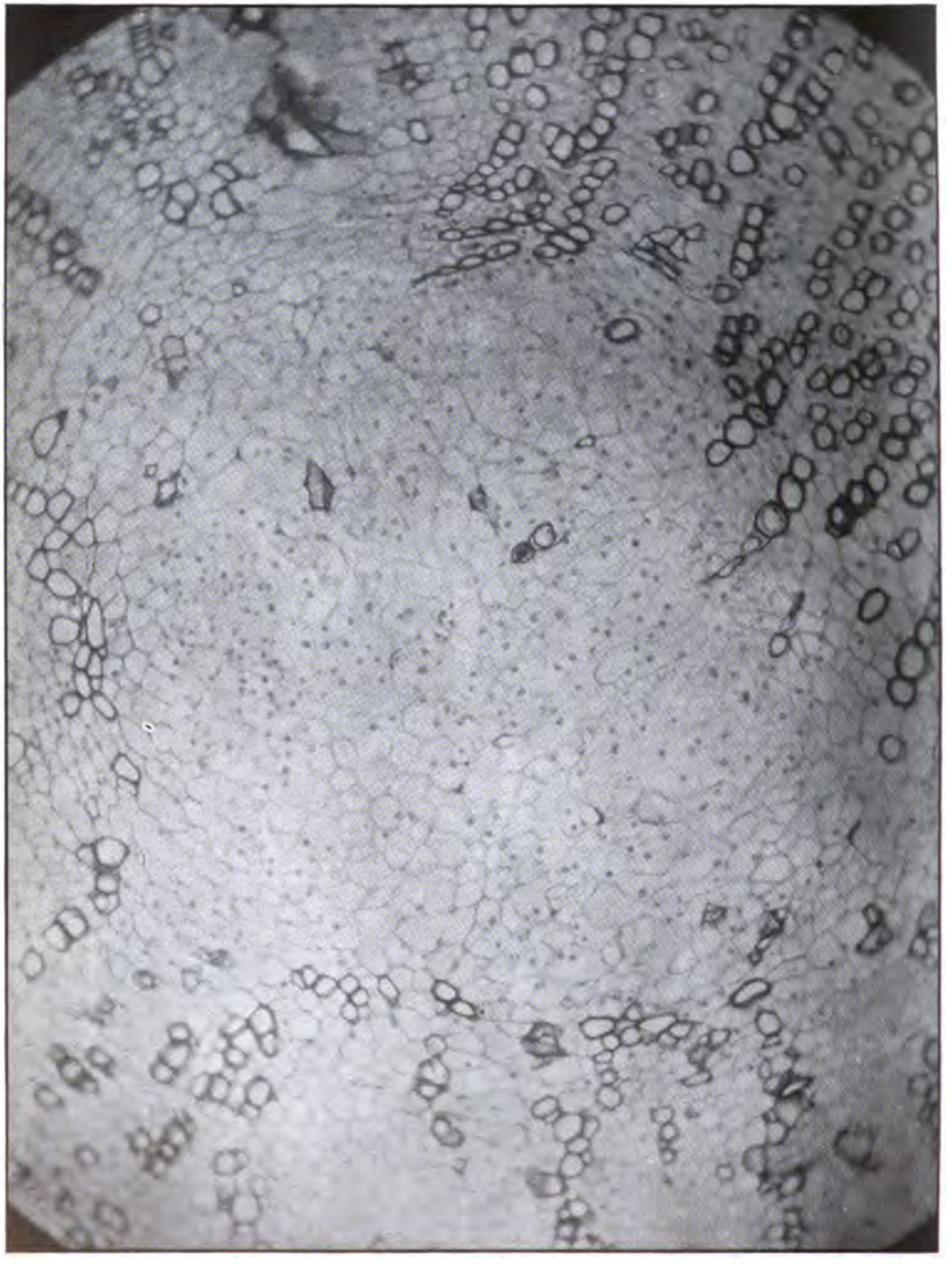

Daisy XI. Inoculated plant, showing primary stem tumor and secondary leaf tumors (p. 33).



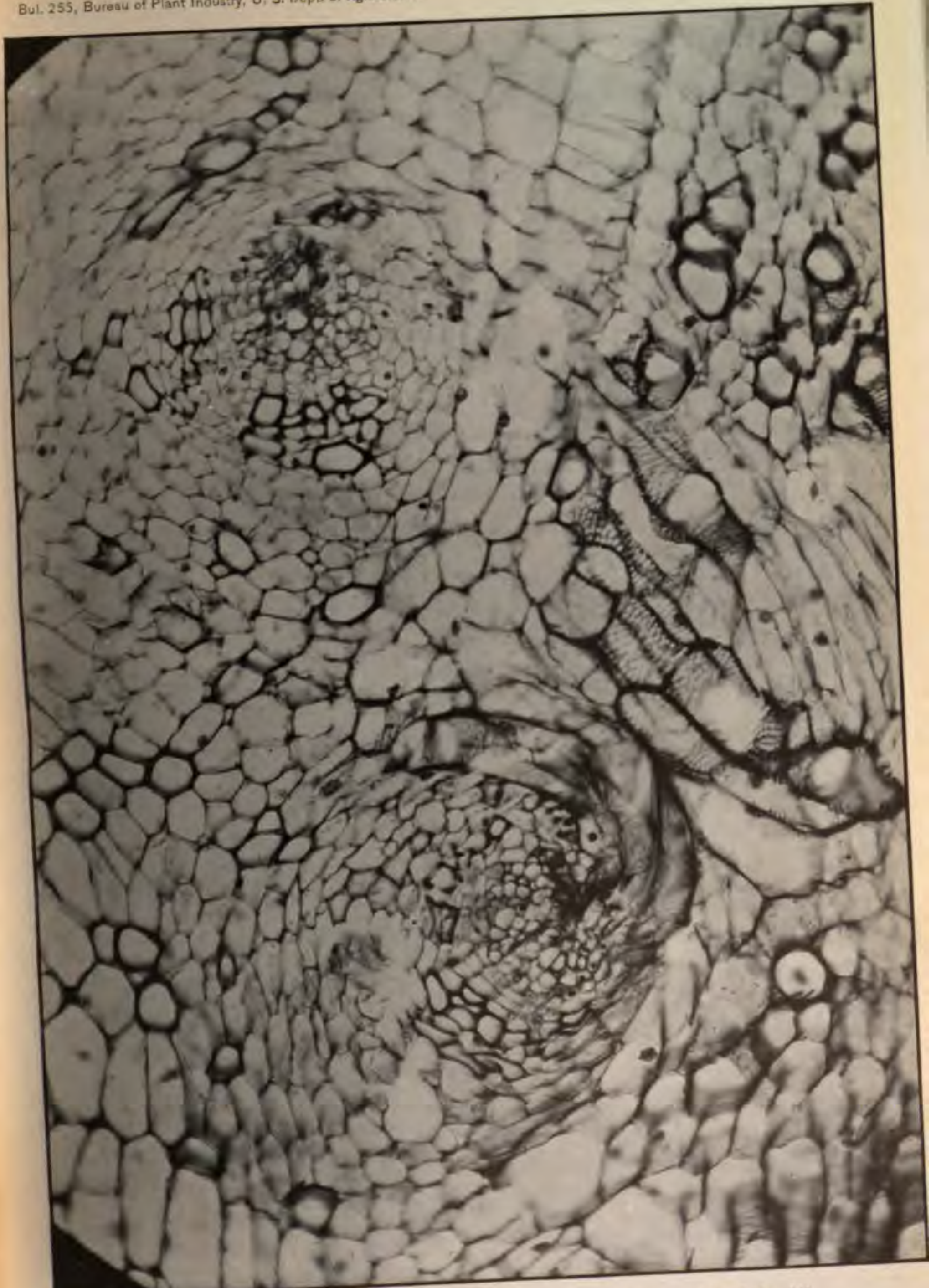
Daisy XI. Cross section of stem in vicinity of P, showing strand (p. 34).



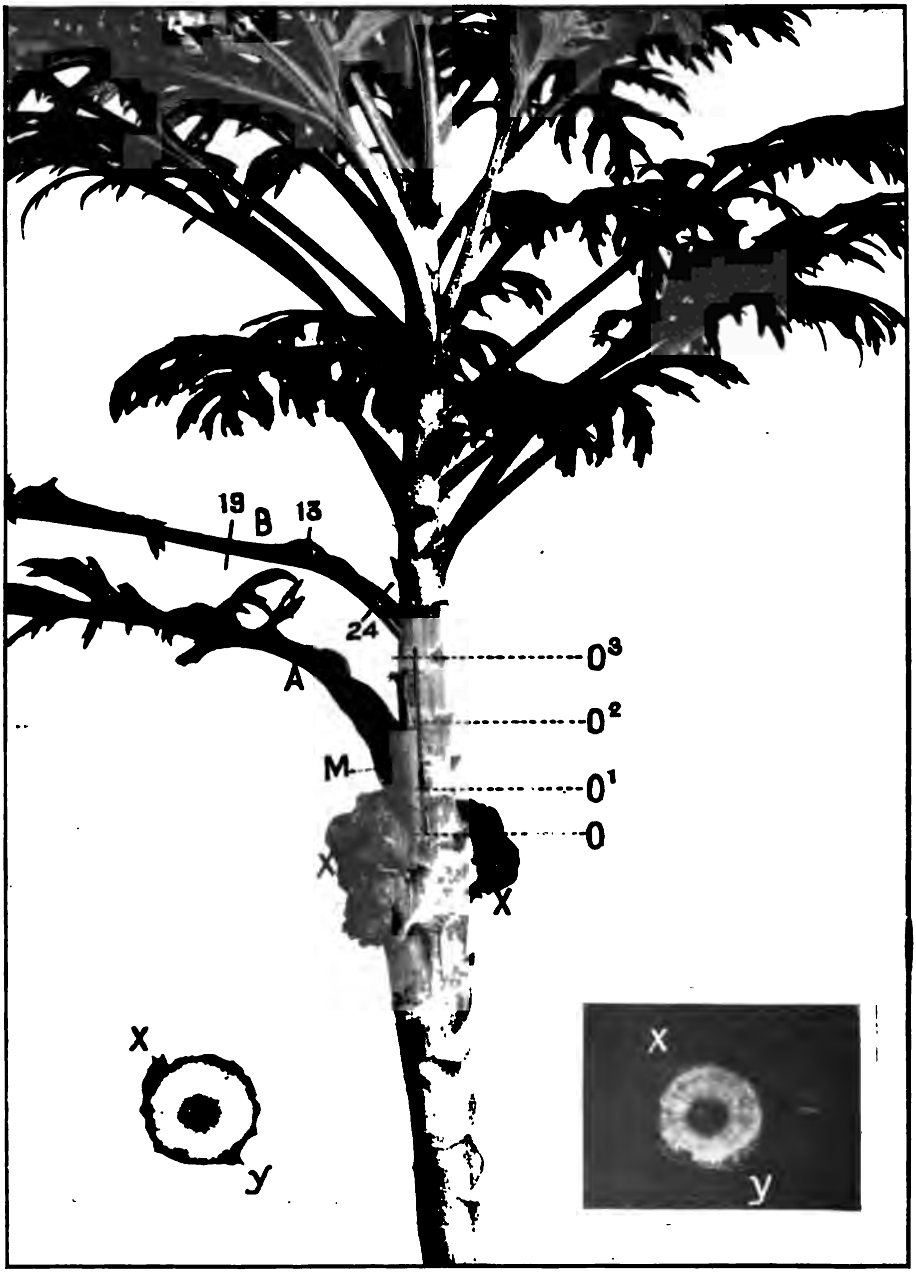
Daisy XI. Cross section of petiole B at M (Pl. XXXII), showing stem tumor in center (p. 34).



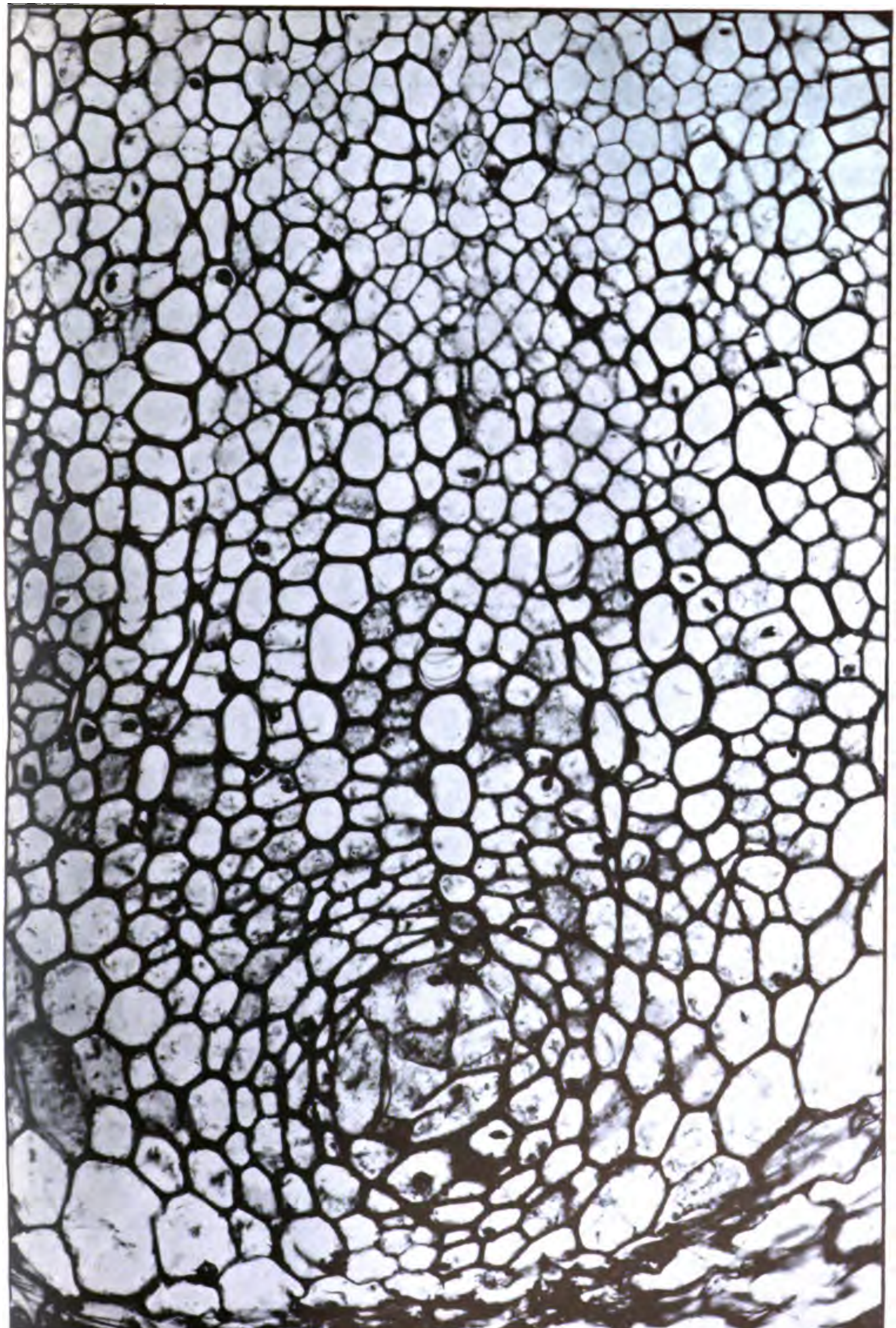
Daisy XI. Cross section of tumor-strand in center of Plate XXXIV, showing tracheids therein and torn and crushed spirals (p. 34).



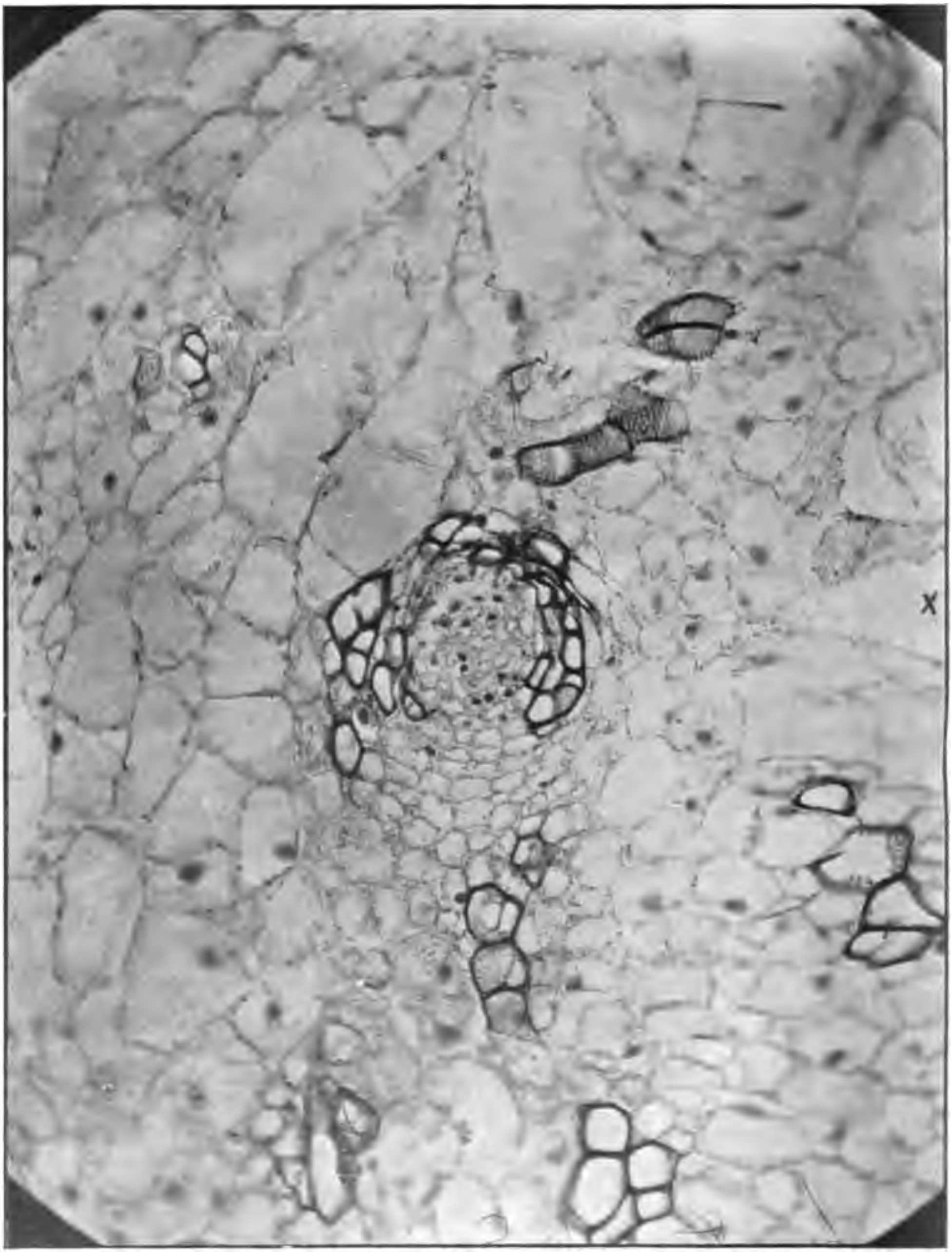
Daisy XI. Whorls of tumor tissue and twisted tracheids in petiole B (p. 34).




Daisy XII. Primary tumor and secondary tumors; also enlarged cross section of secondary tumor in a leaf (p. 35).

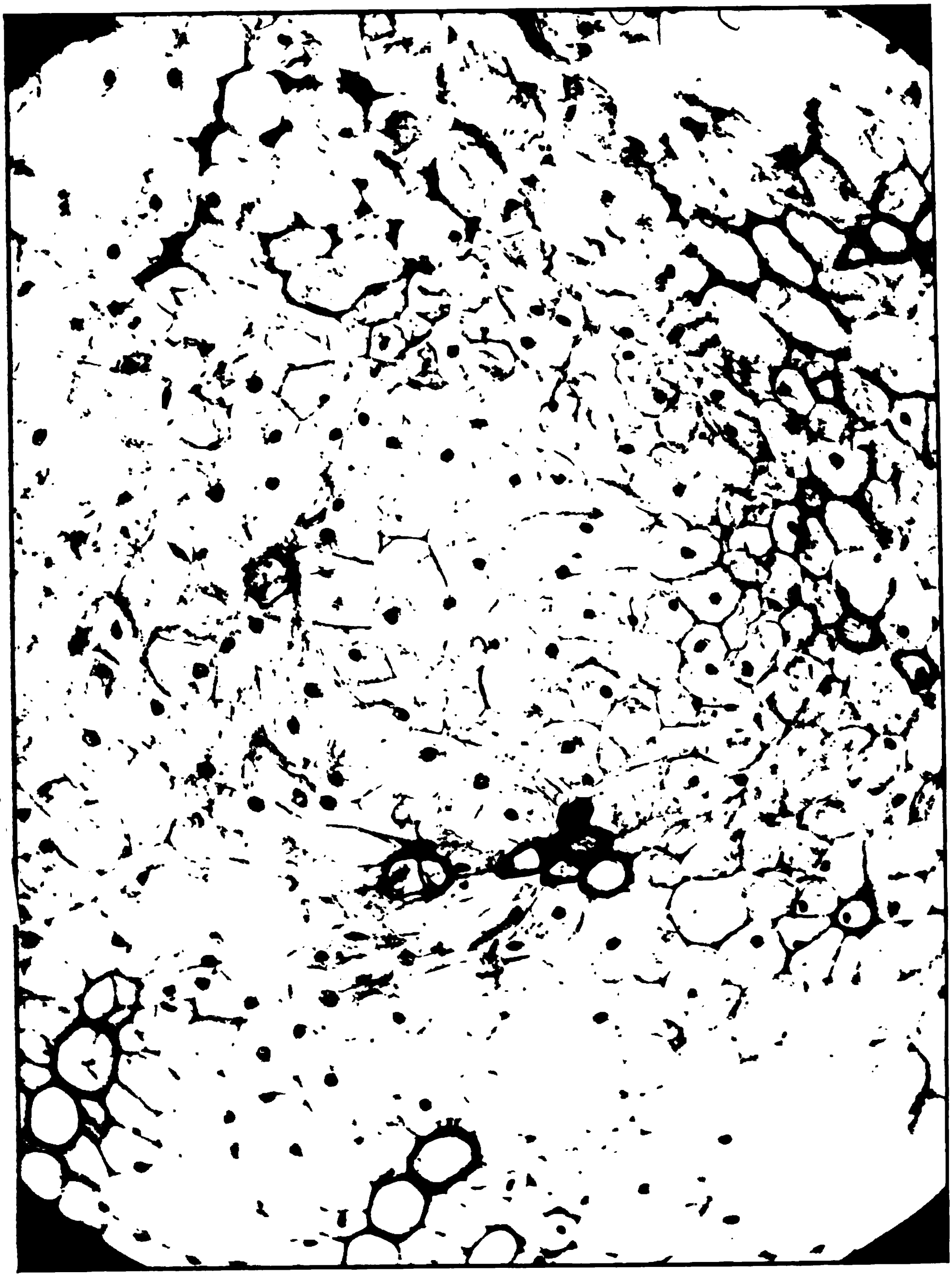


Daisy XII. Cross section of stem between tumors, showing tumor-strand (p. 35).

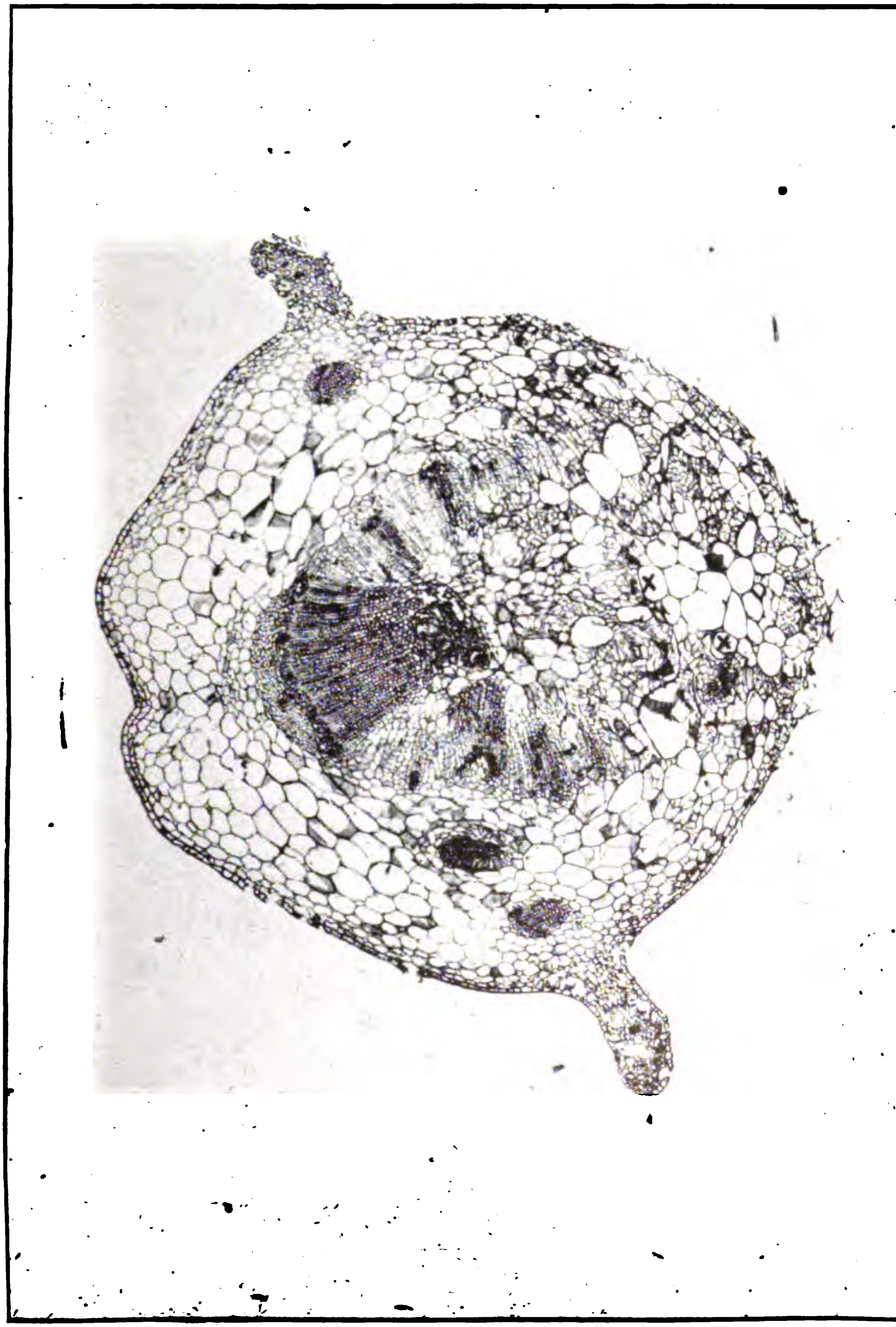



Daisy XII. Cross section of petiole A; whorl in tumor tissue (p. 36).

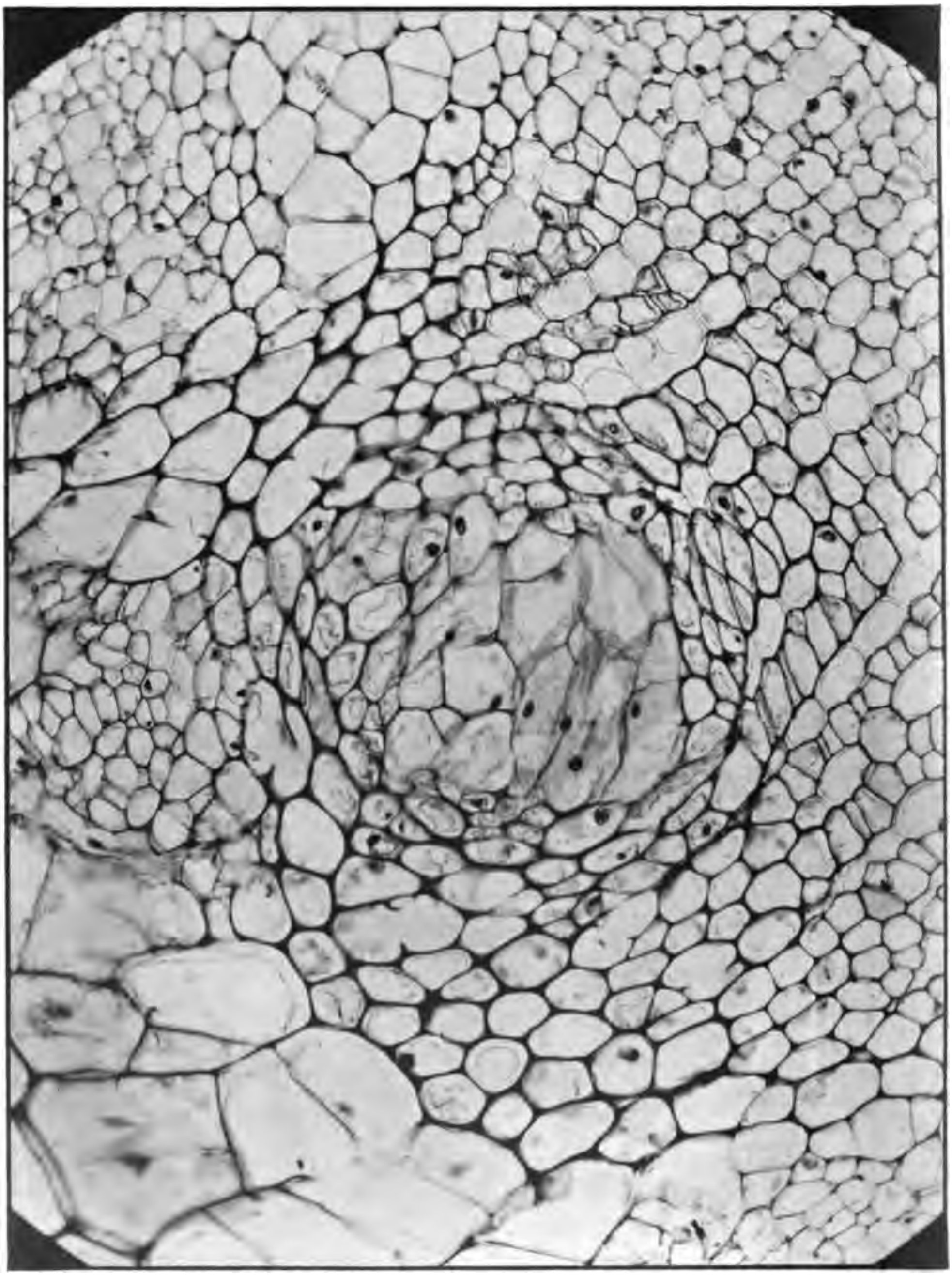

Daisy XII. Joins onto Plate XXXIX; another whorl in the tumor, X joins X (p. 36).



Daisy XII. Cross section of tumor-strand in petiole A, showing displaced vessels in the strand (p. 36).

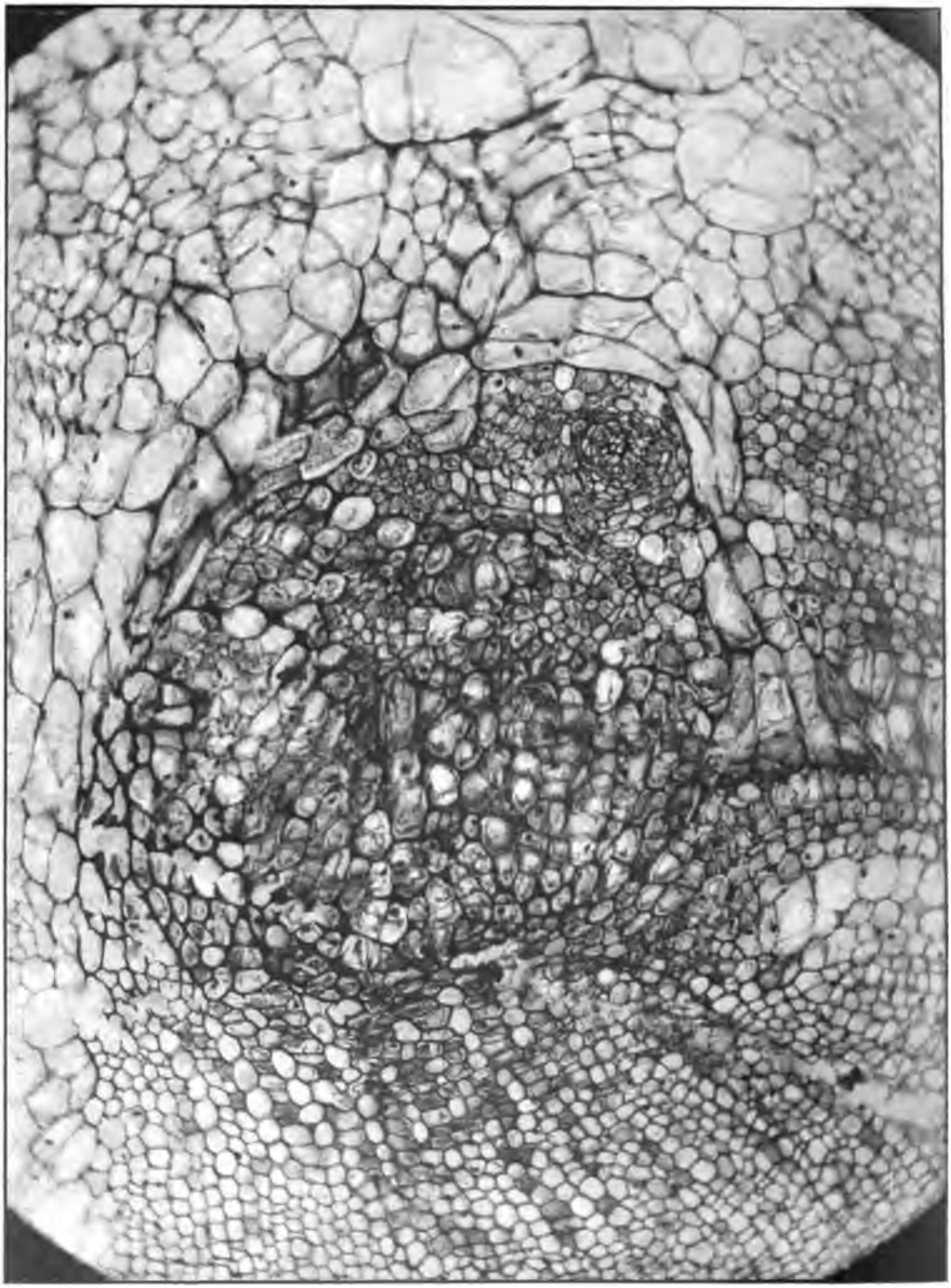


Daisy XII. Cross section of petiole B, showing a growing secondary tumor with cell inclusions (p. 36).

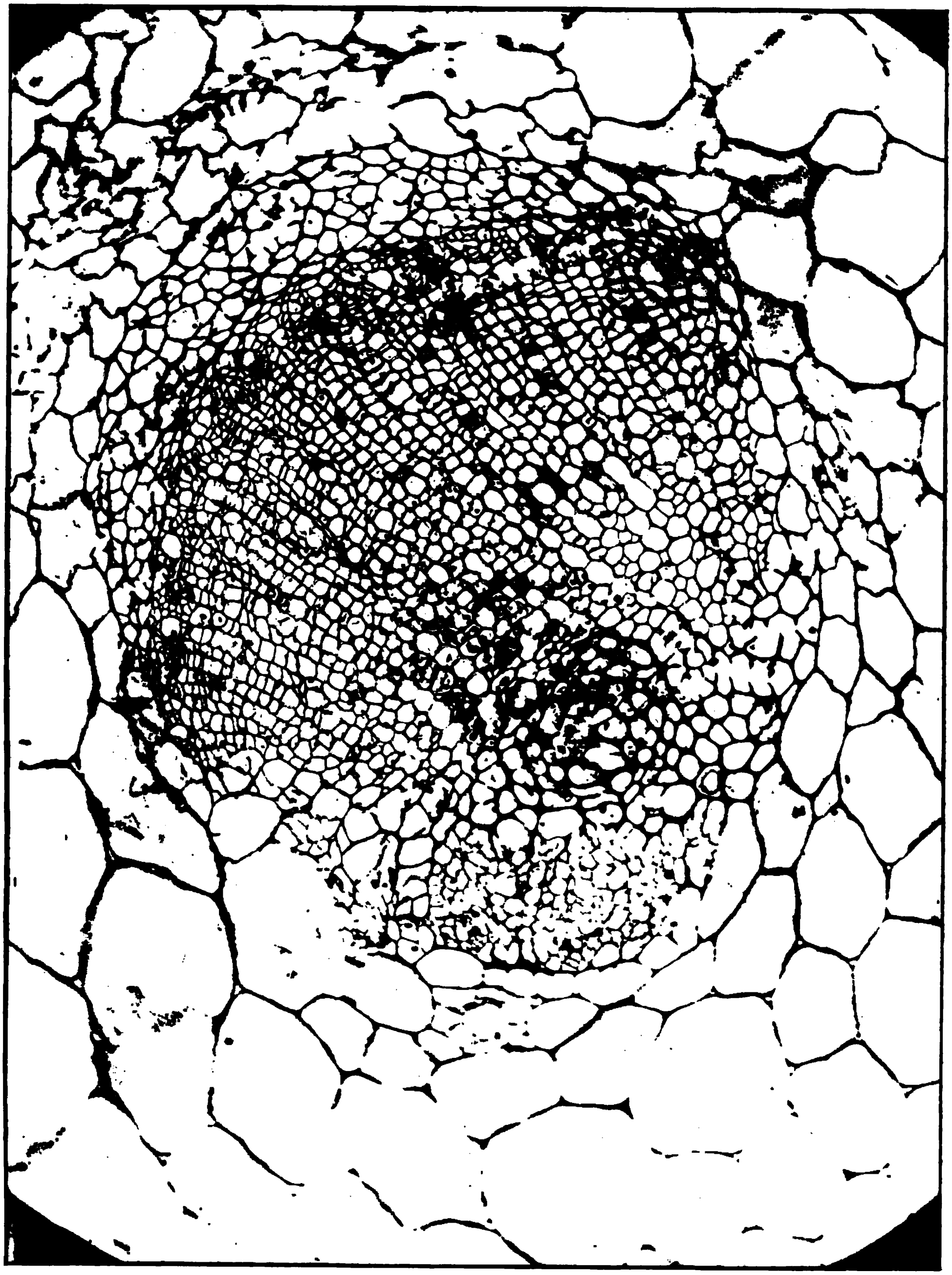


Daisy XII. Cross section, tumor-strand in petiole B, near XLII (p. 37).

Daisy XII. Cross section of petiole B at another level, showing cell inclusions and large tumor-strand, with normal part of leaf-trace at left (p. 37).



Daisy XII. Tumor-strand from Plate XLIV; large and small cells present; abnormal medullary ray at right (p. 37).

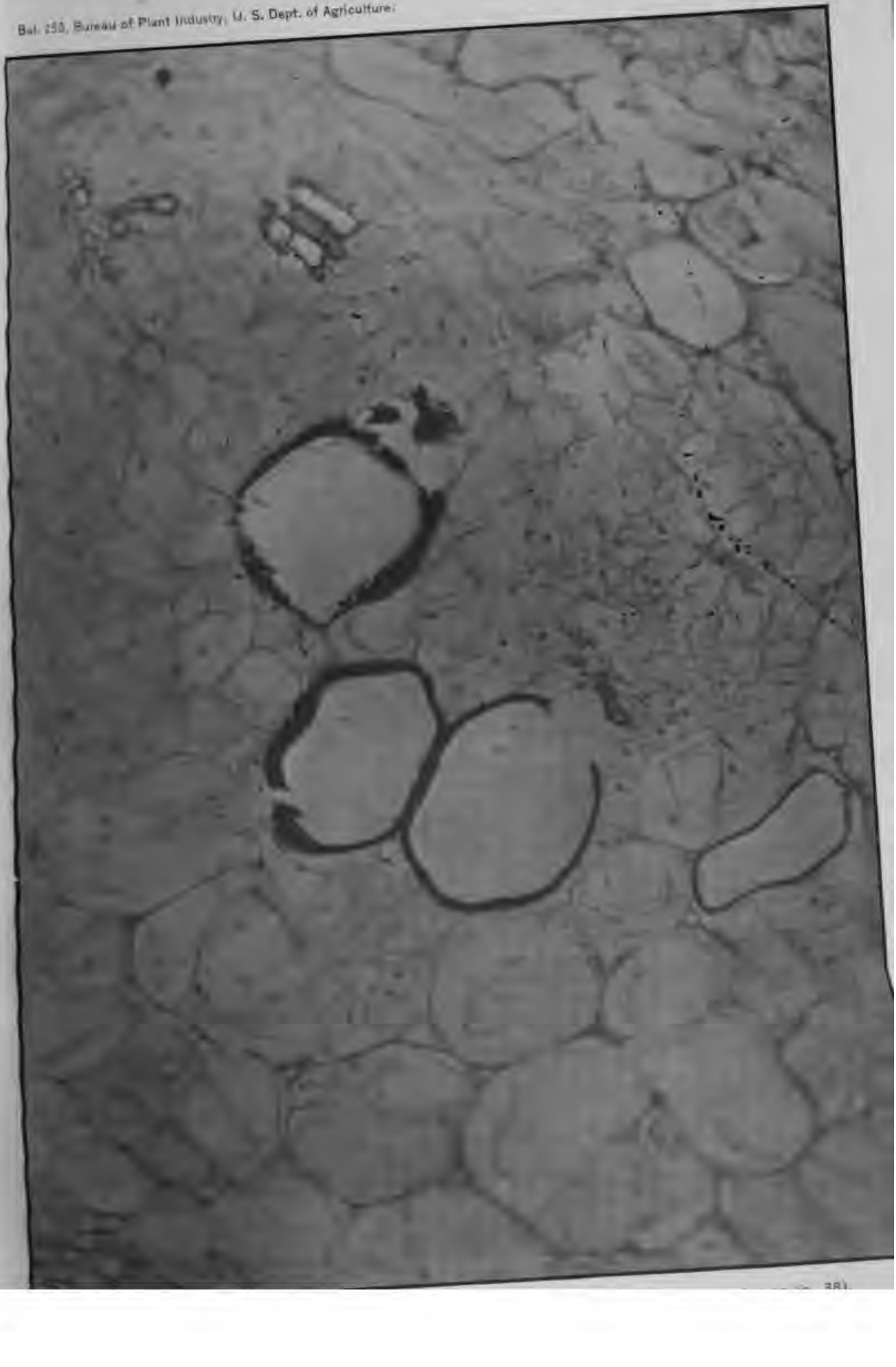


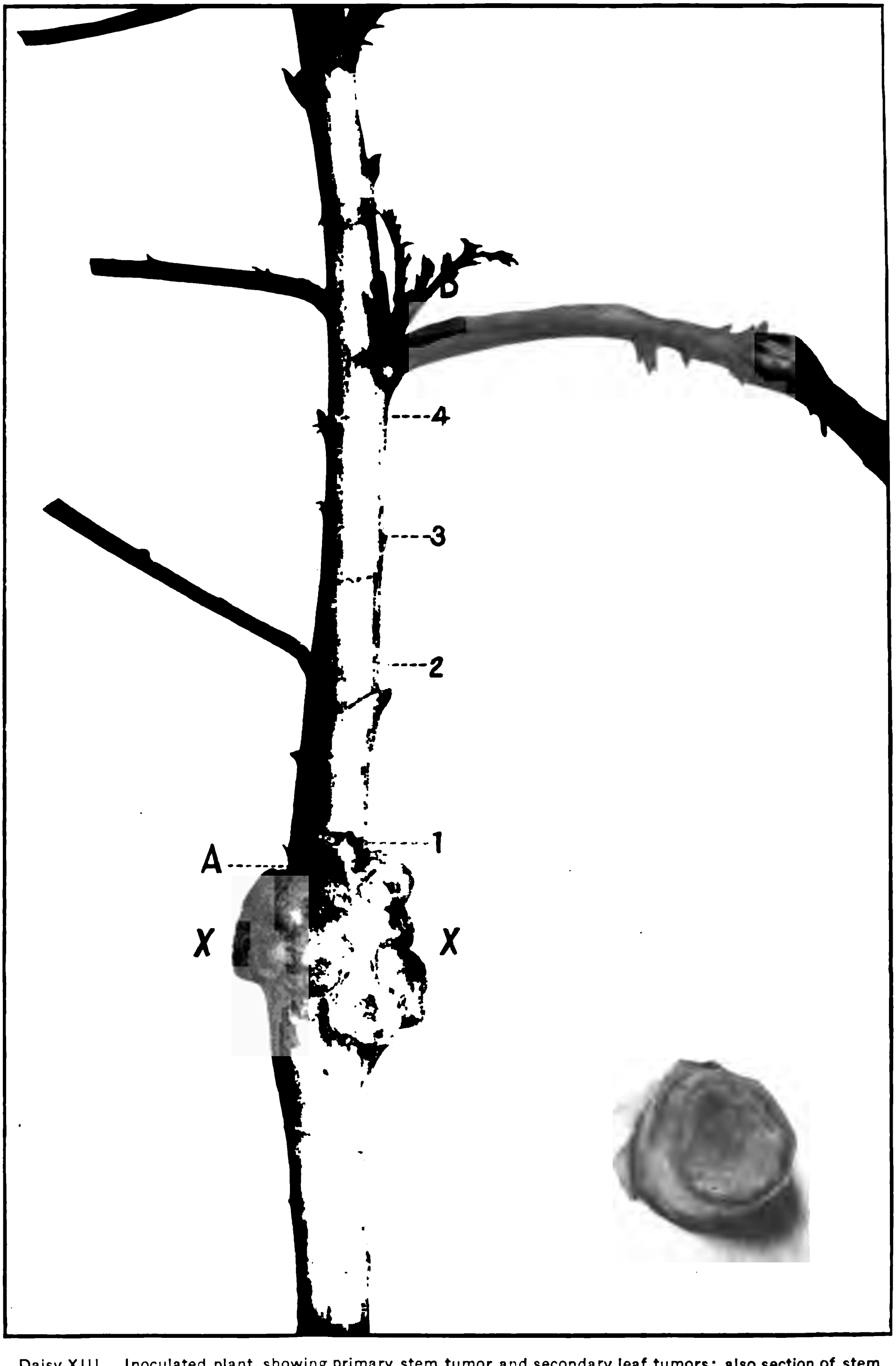
Daisy XII. Infected leaf-trace far out on petiole B (p. 37).

Daisy XII. Cross section of lower part of petiole B, showing incipient tumor in the central leaf-trace (p. 38).

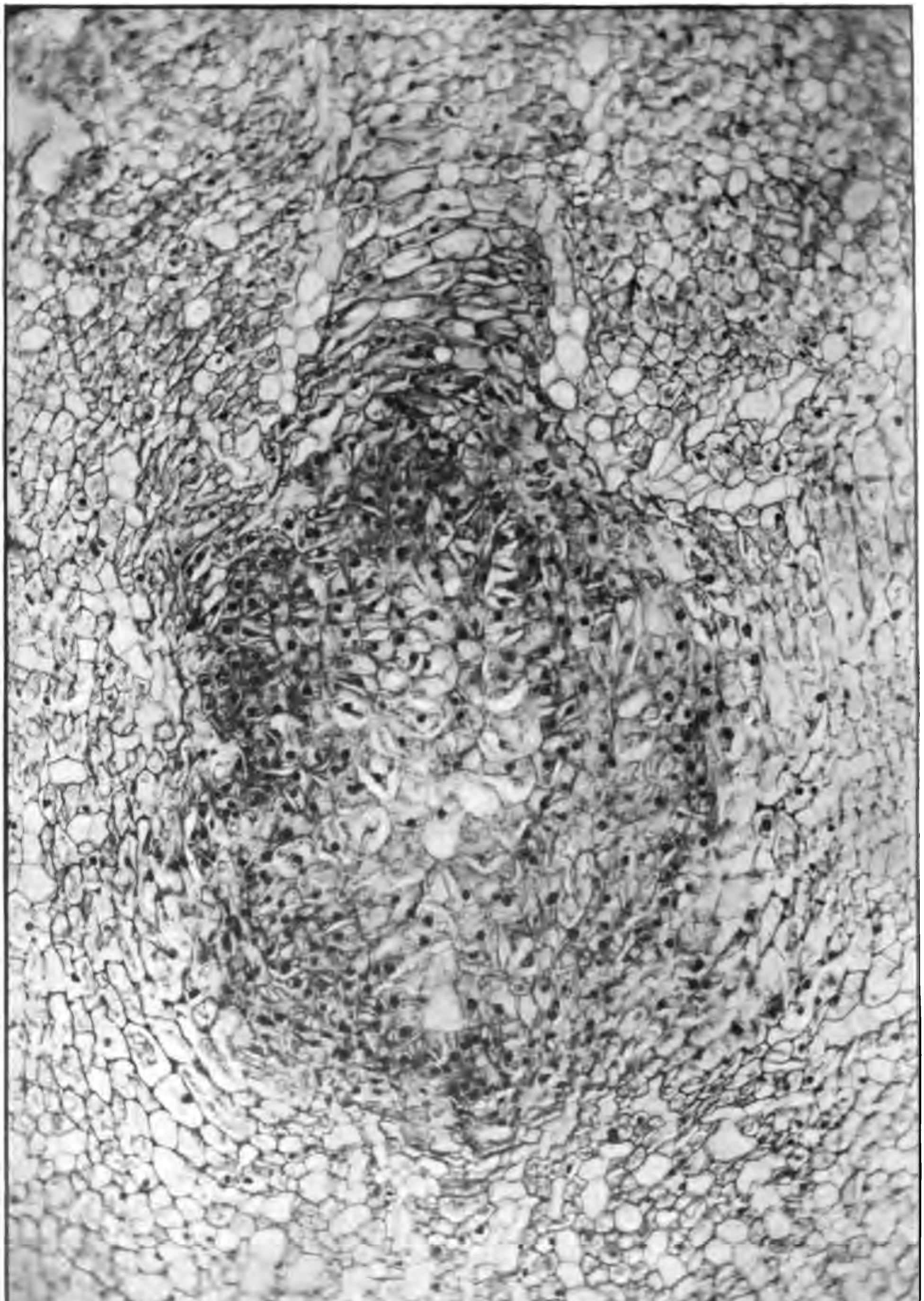

Daisy XII. Cross section of central leaf-trace of petiole B, further enlarged for comparison with Plate III (p. 38).


Daisy XII. Longitudinal section of leaf-trace shown in Plate XLVIII, all abnormal except sp and scl (p. 38).



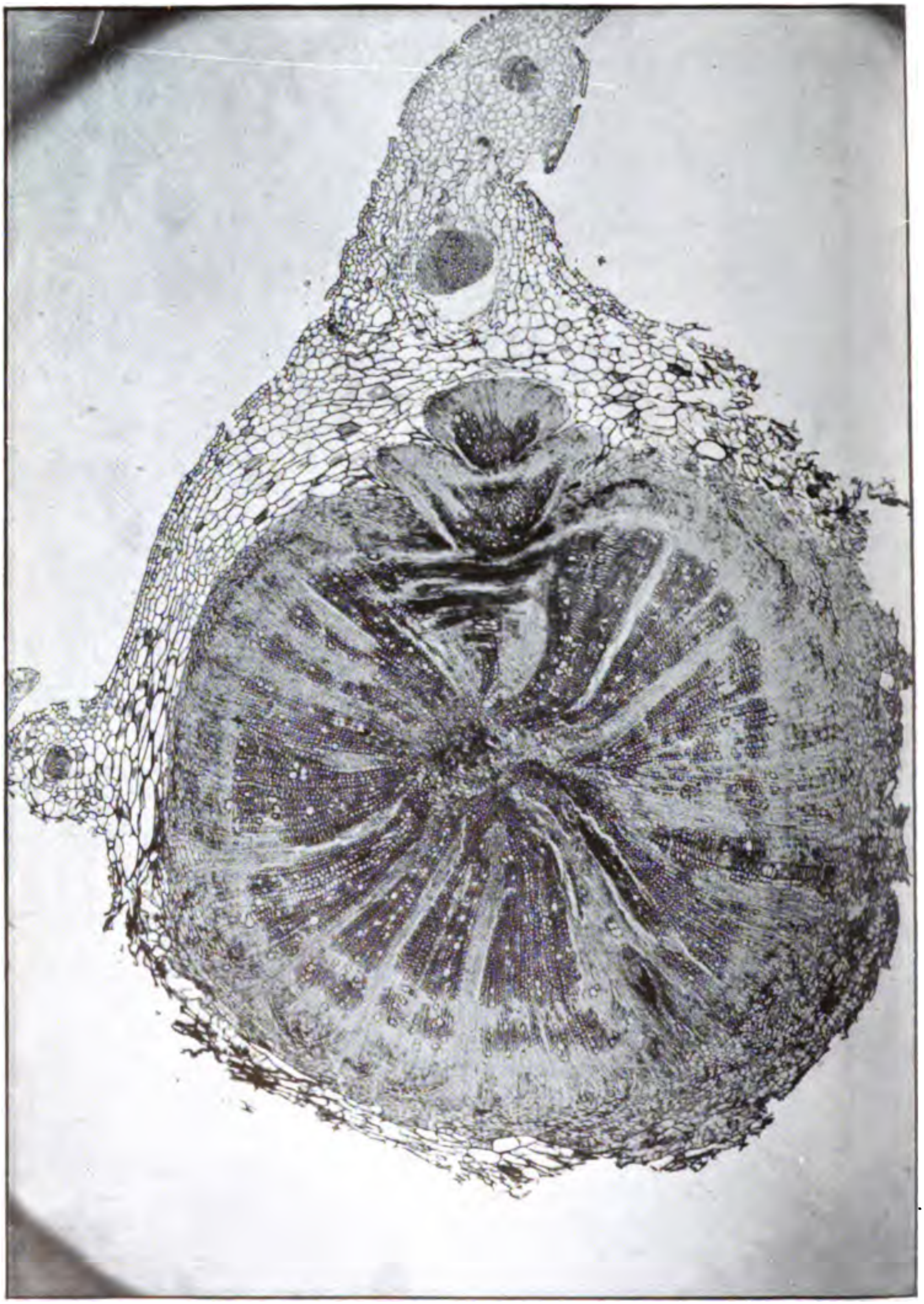



Daisy XIII. Inoculated plant, showing primary stem tumor and secondary leaf tumors; also section of stem at fig. 2 (p. 39).

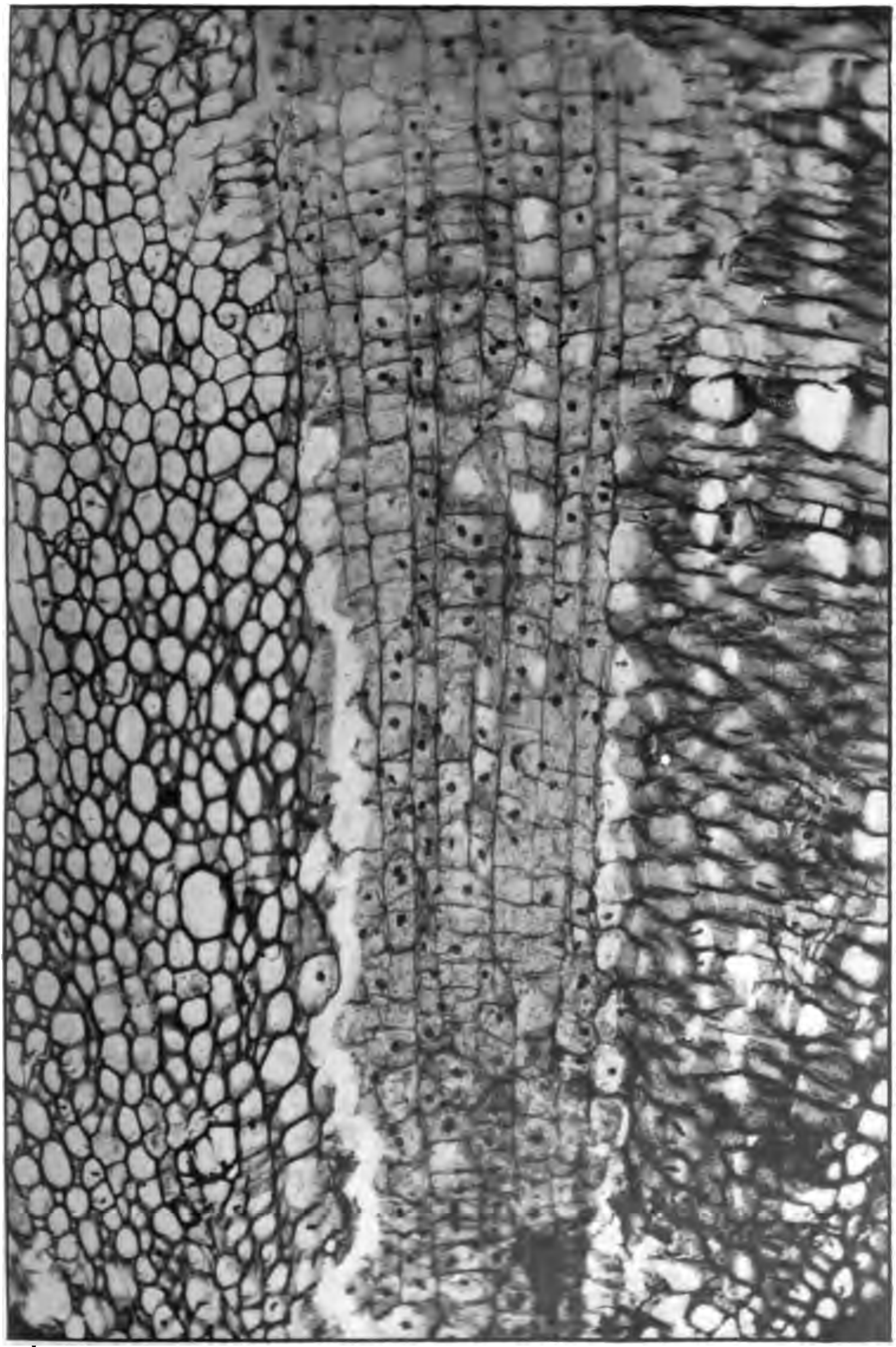


Daisy XIII. Tumor-strand enlarged from Plate LII, nuclei deeply stained (p. 40).

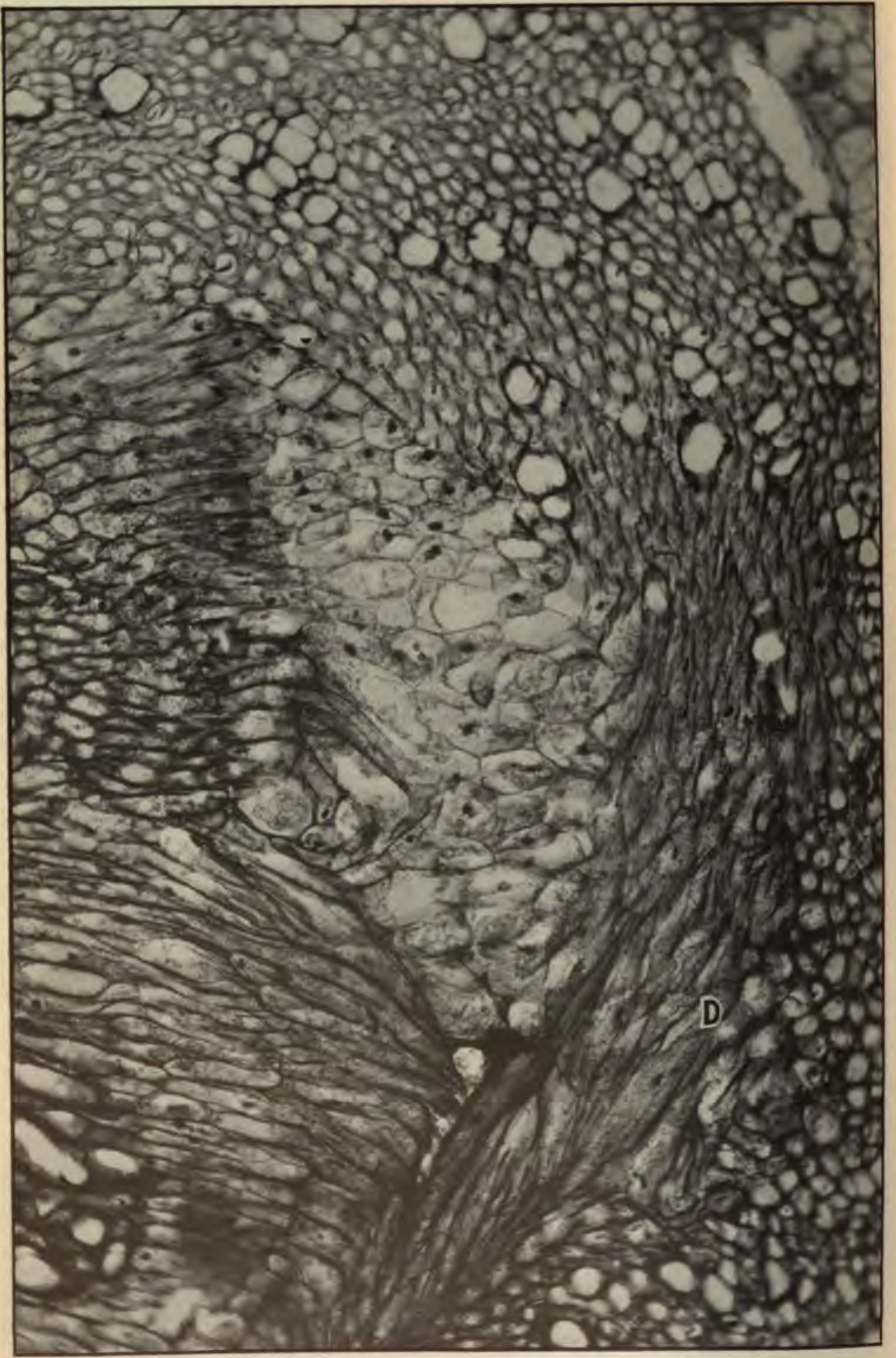

Daisy XIV. Portion of inoculated plant, showing primary stem tumor and secondary leaf tumors (p. 40).



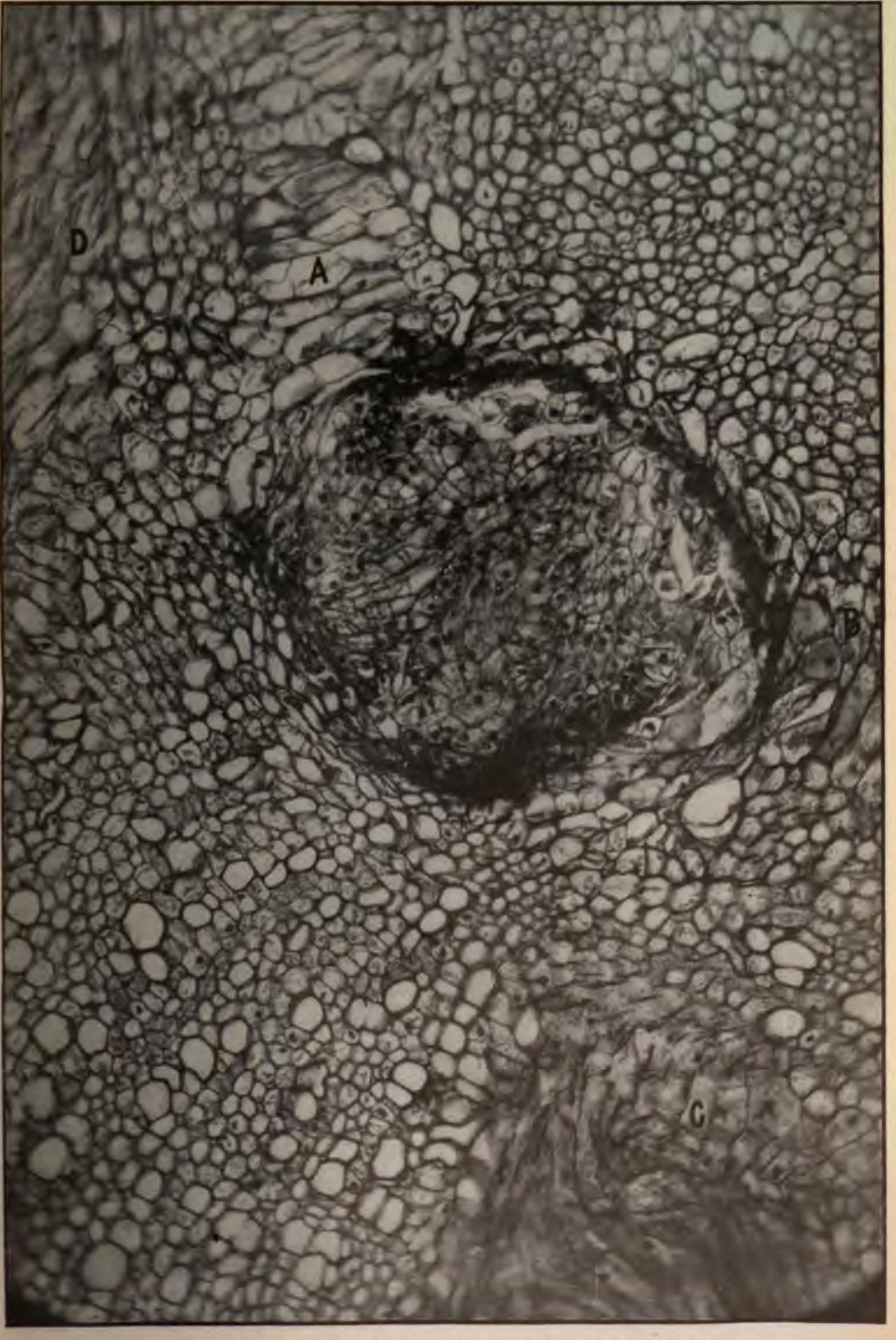
Daisy XIV. Cross section of petiole C, showing secondary tumor with stem structure. What remains of the normal tissue is above and at the left (p. 40).



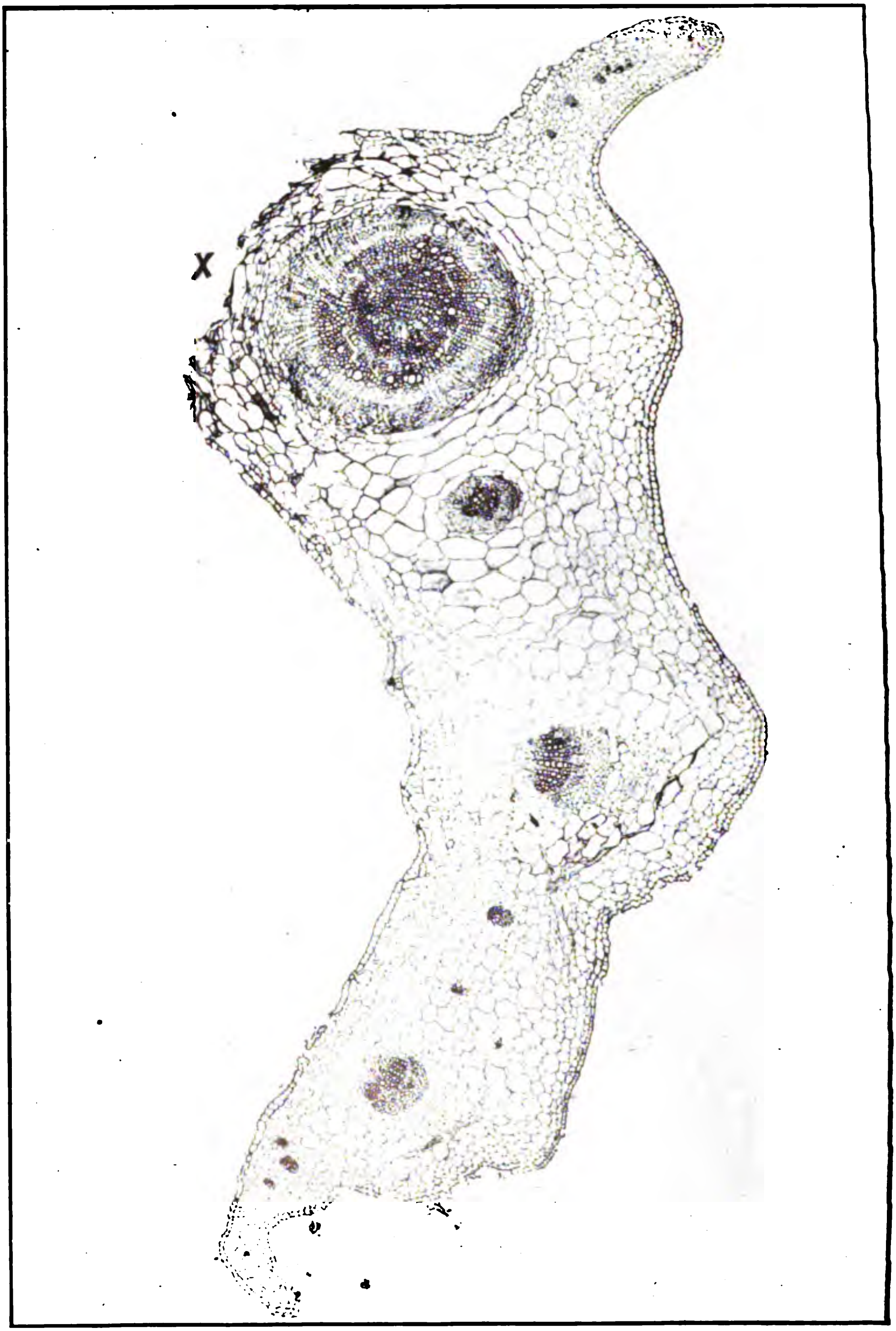
Daisy XIV. Cross section of petiole C, showing abnormal medullary ray with normal and abnormal tracheids (p. 41).



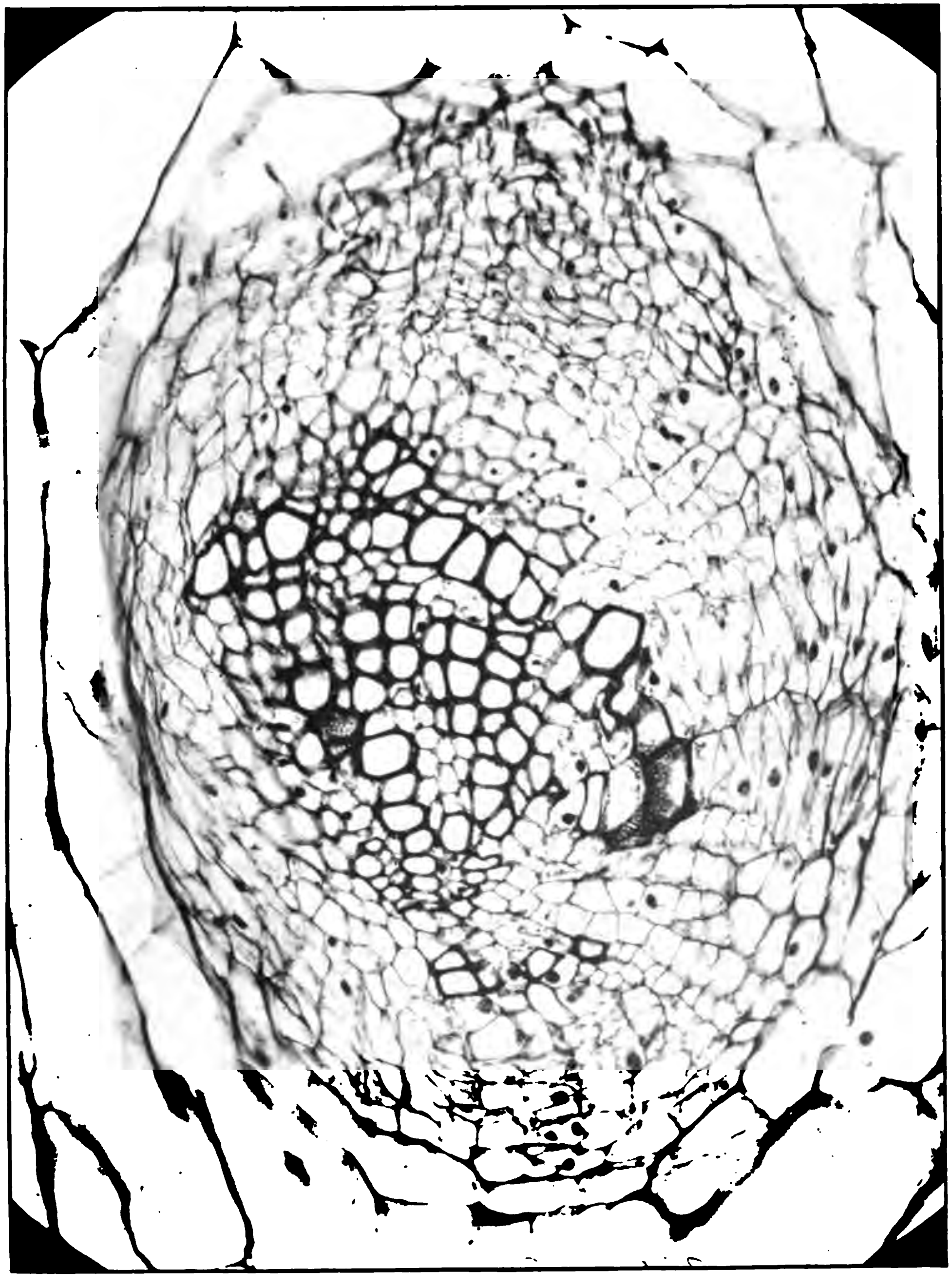

Daisy XIV. Hypertrophied cells in tumor in petiole C (p. 41).




Daisy XIV. Cross section of the tumor-strand in petiole C (p. 41).

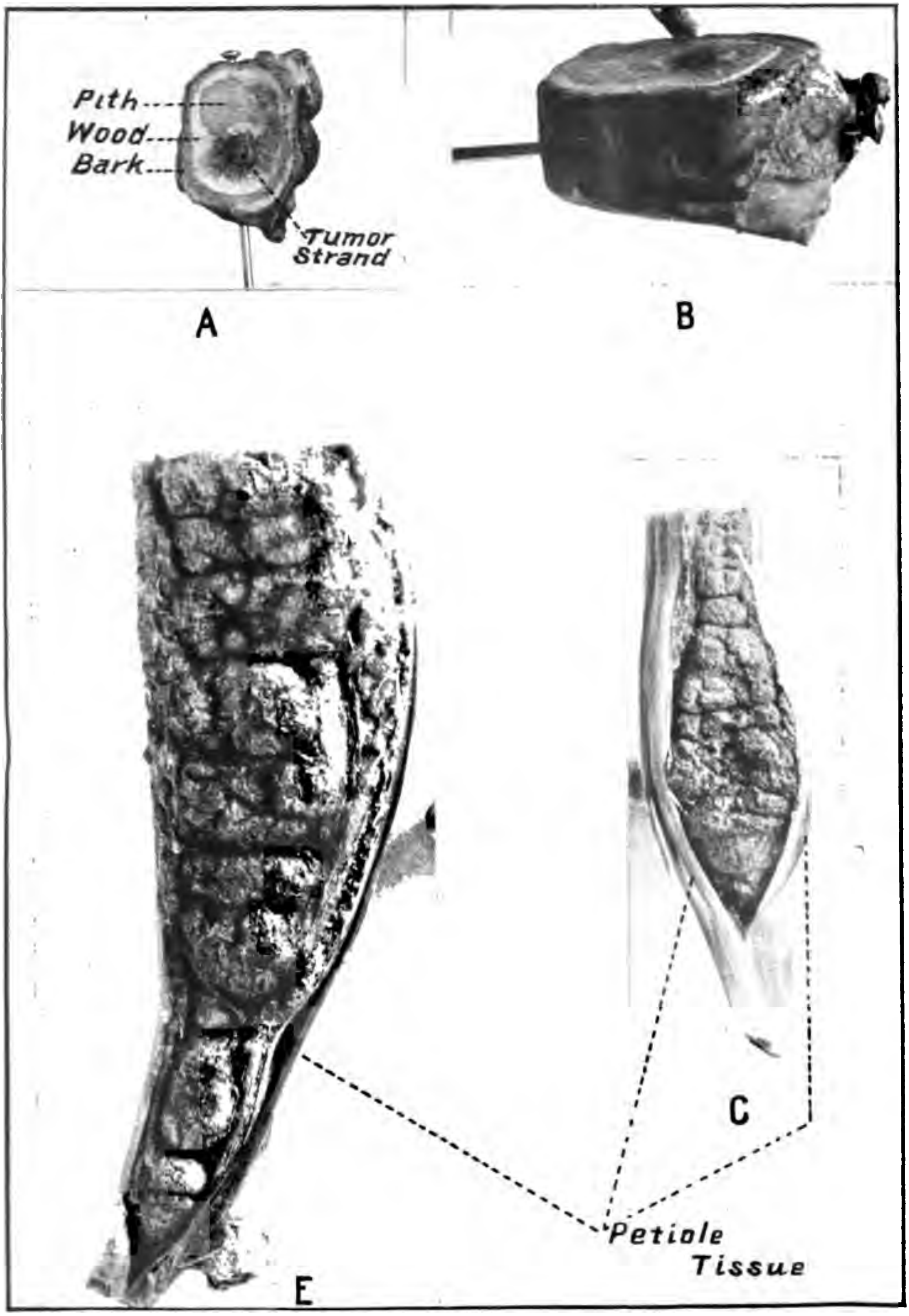



Daisy XIV. Cross section of petiole B, showing a secondary tumor with stem structure at X in a lateral leaf-trace (p. 41).



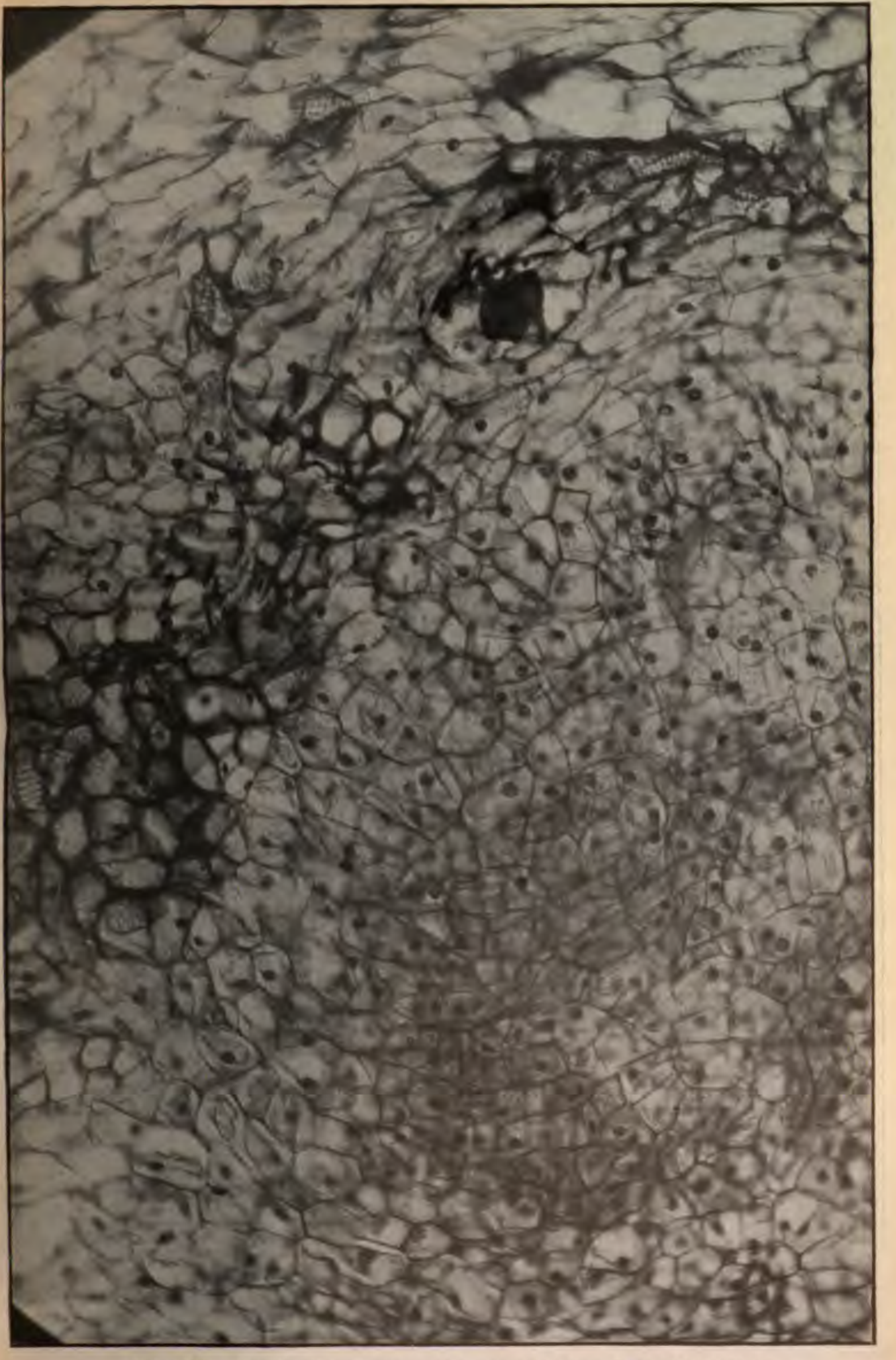
Daisy XIV. Petiole B, showing disturbance in leaf-trace next below X of Plate LIX (p. 42).


Daisy XVI. Inoculated plant, showing primary stem tumor and secondary leaf tumors (p. 42).

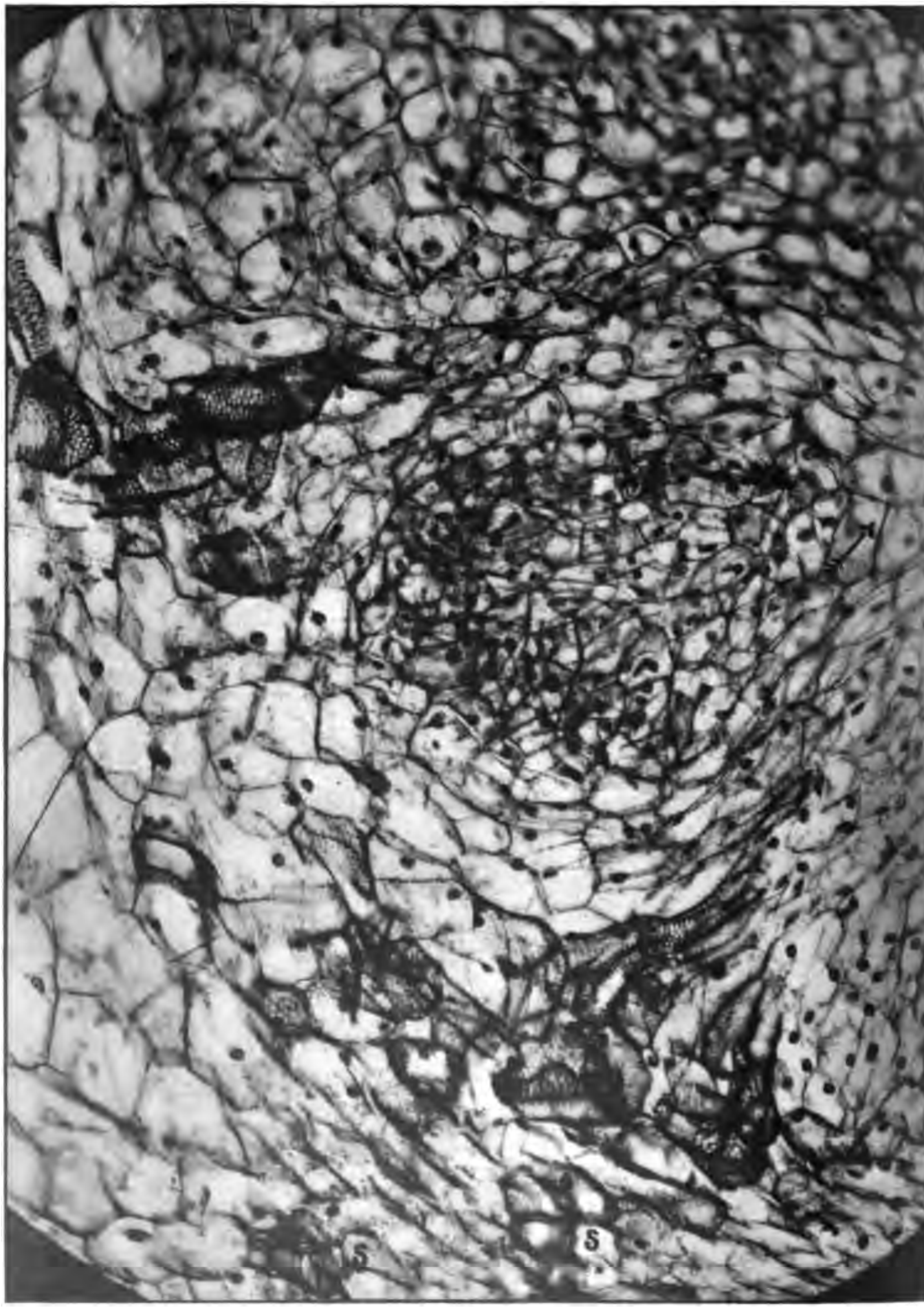



Daisy XVI. Cross section of stem between tumors, showing protrusion of tumor-strand; also petioles enlarged to show how the secondary tumor reaches the surface, i. e., by splitting open the overlying tissues (p. 42).

Daisy XVI. Magnified cross section of stem between tumors; tumor-strand at left; wood cylinder thickened in three-fourths of its circumference (p. 43).



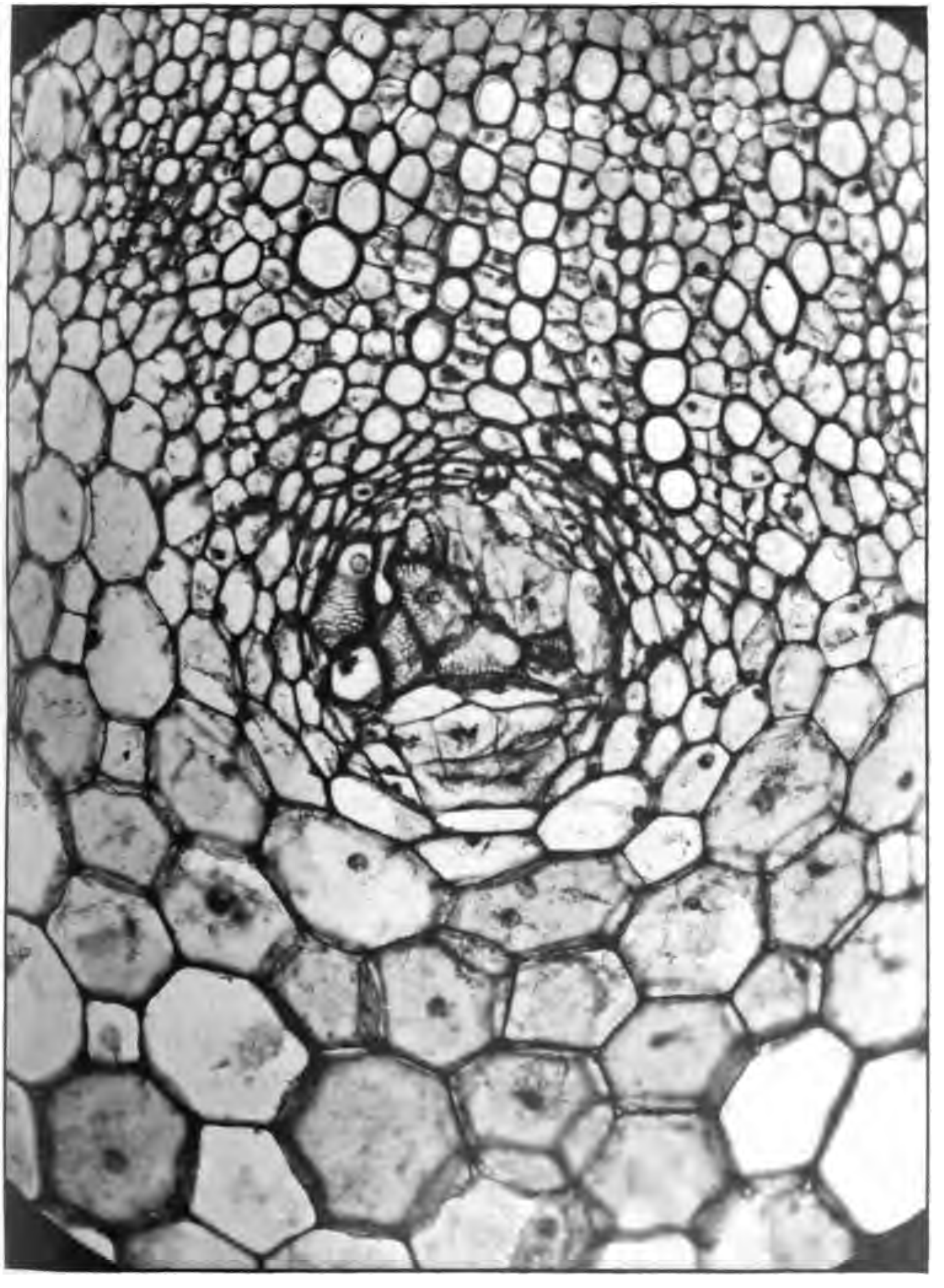
Daisy XVI. Margin of small portion of tumor-strand from Plate LXIII (p. 43).



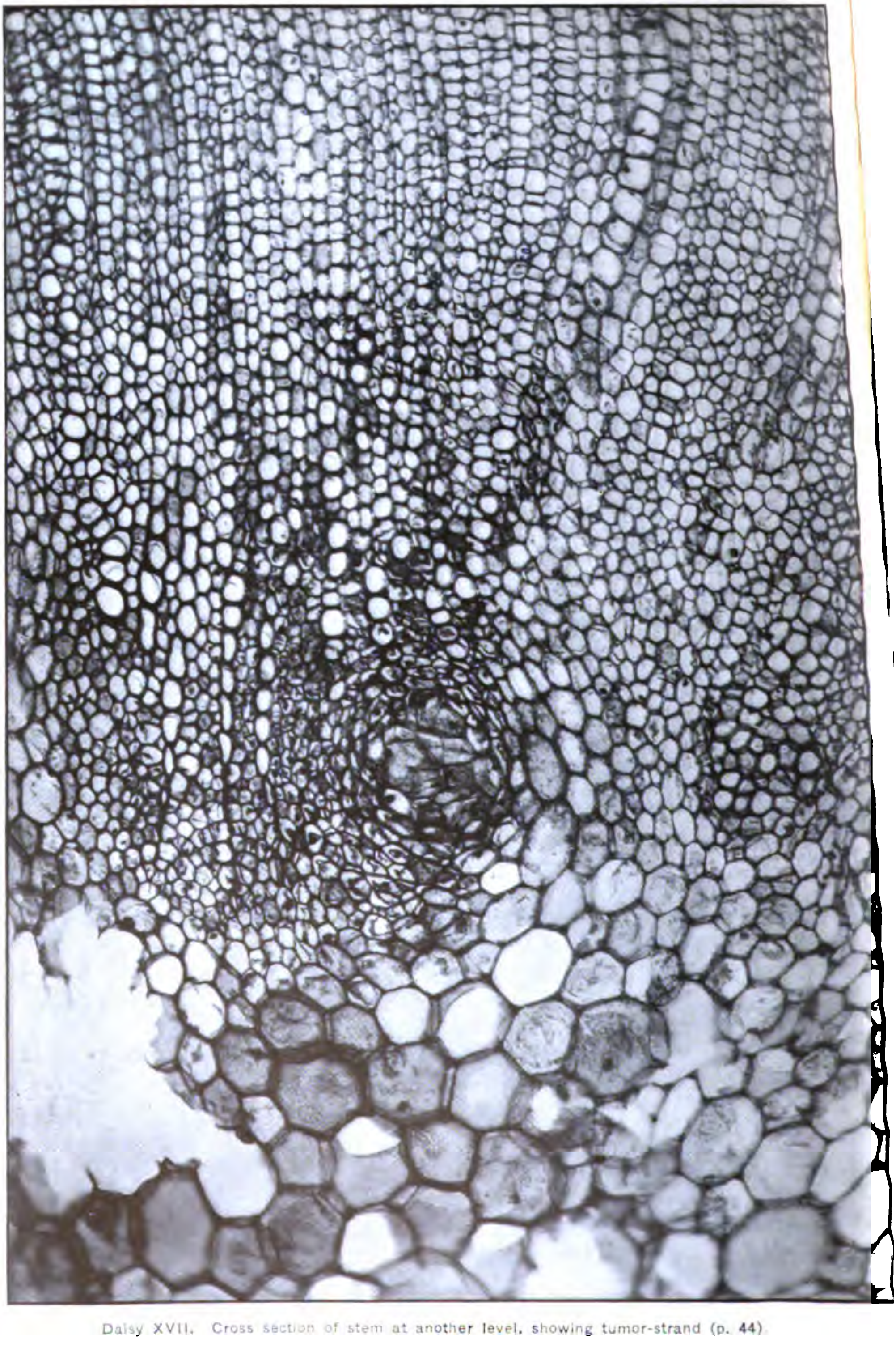

Daisy XVI. Tumor-strand and stroma of twisted tracheids, spirals at S, with remainder of them in direction of the arrow (p. 43).


Daisy XVII. Inoculated plant, showing primary stem tumor and secondary leaf tumors (p. 43).


Daisy XVII. Cross section of stem between tumors, showing a small tumor-strand at X (p. 44).

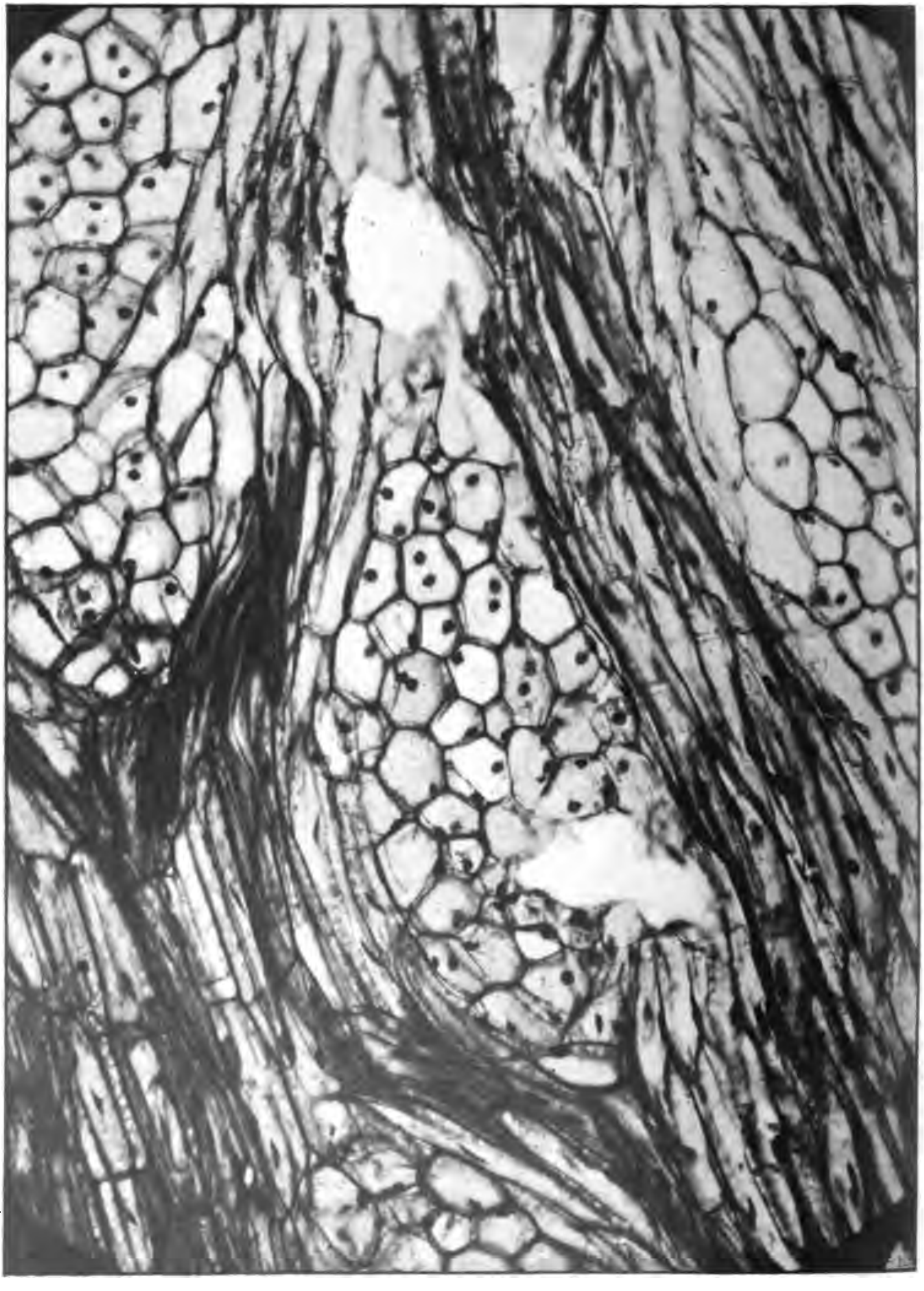


Daisy XVII. Portion of Plate LXVII enlarged, showing tracheids developed in the tumor-strand; the vessels immediately above are spirals (p. 44).

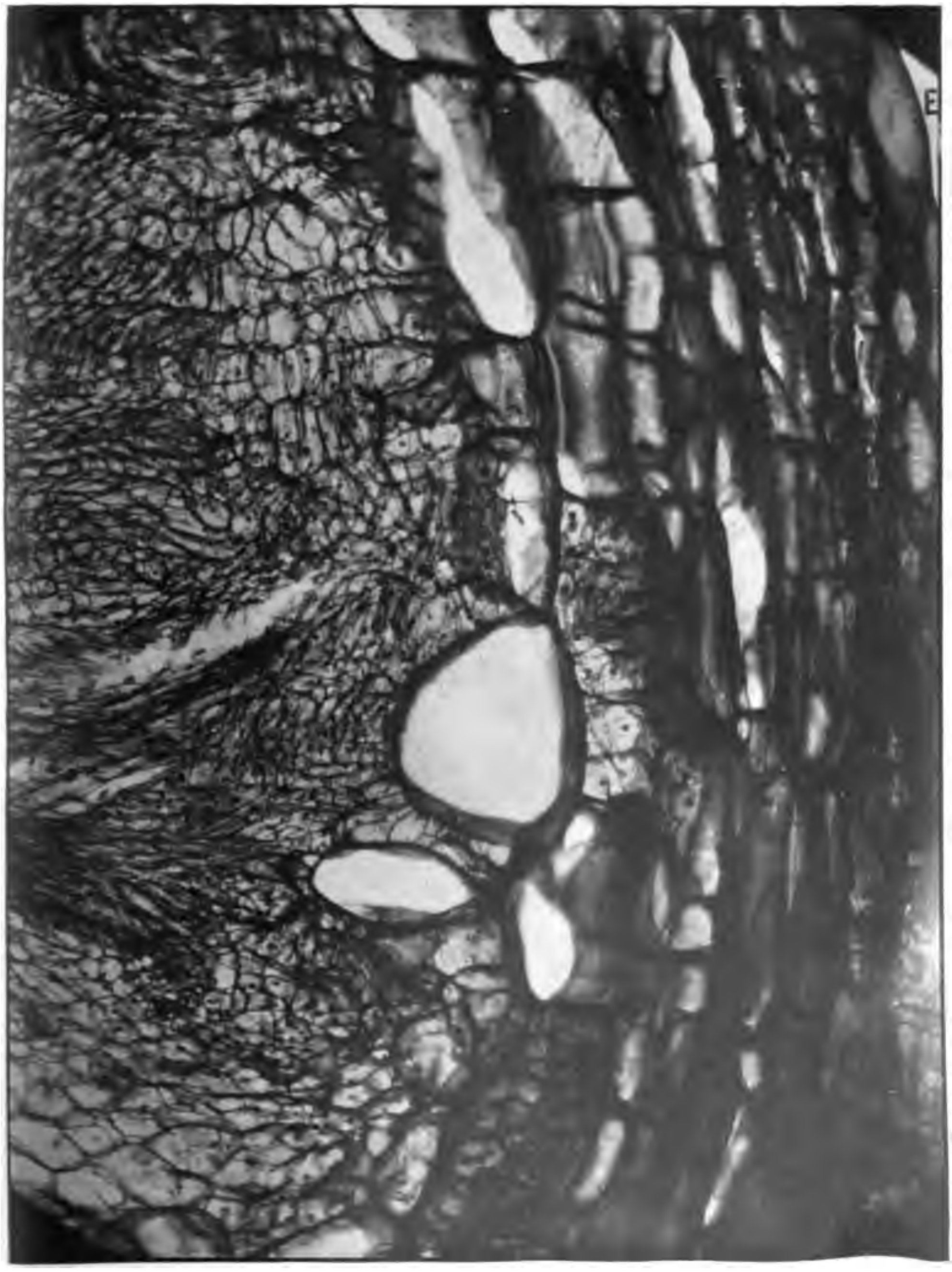


Daisy XVII. Cross section of stem at another level, showing tumor-strand (p. 44).

Daisy XVII. Longitudinal section of petiole C, showing tumor-strand (p. 44).



Daisy XVII. Tumor tissue of petiole C with bi- and tri-nucleate cells (p. 45).

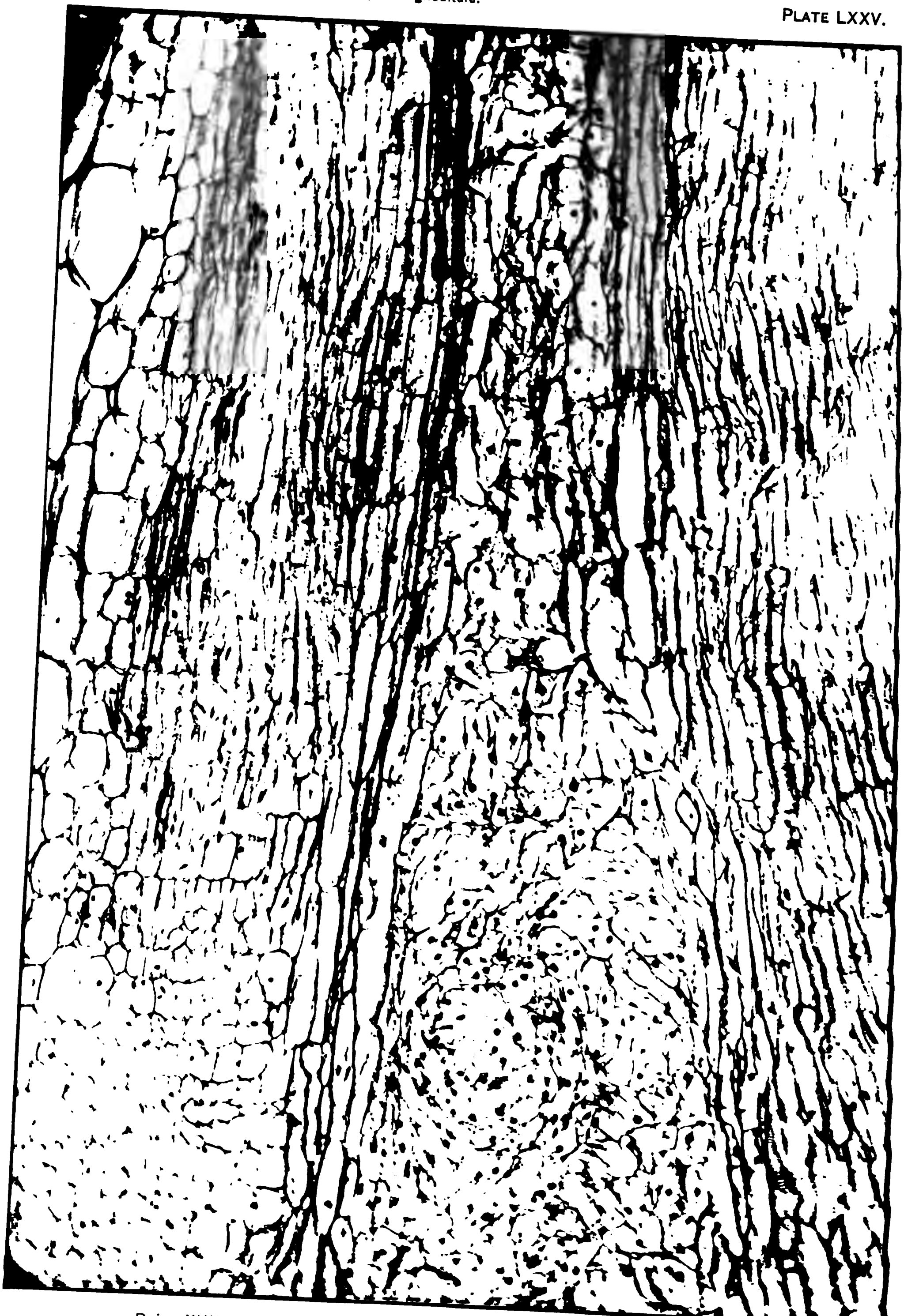



Daisy XVII. Margin of secondary tumor (petiole C) showing infiltration (p. 45).


Daisy XVIII. Inoculated plant, showing primary tumor on stem and secondary tumors on leaves (p. 45).

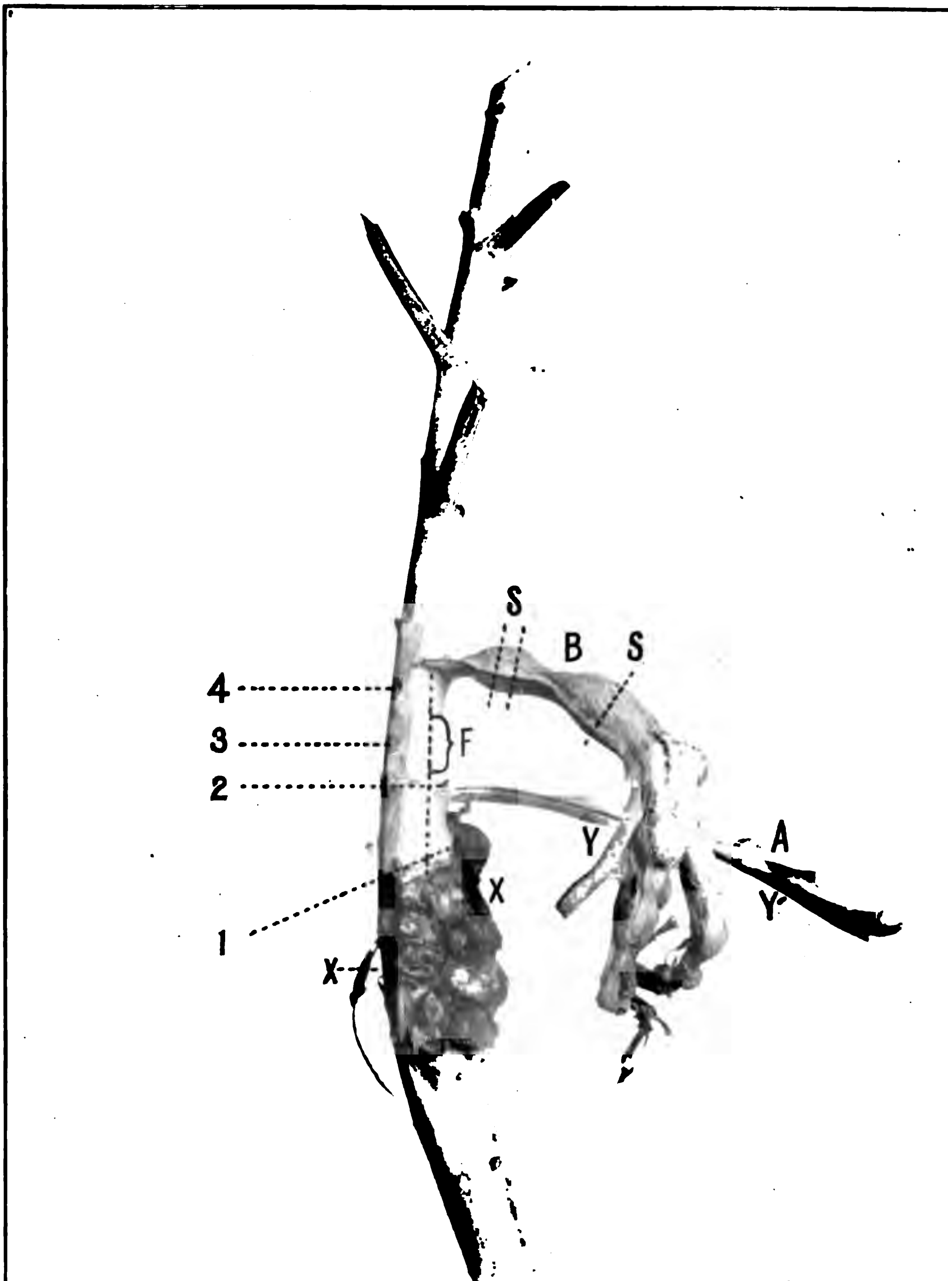
Daisy XVIII. Longitudinal section of petiole A, showing tumor-strand (p. 45).

PLATE LXXV.

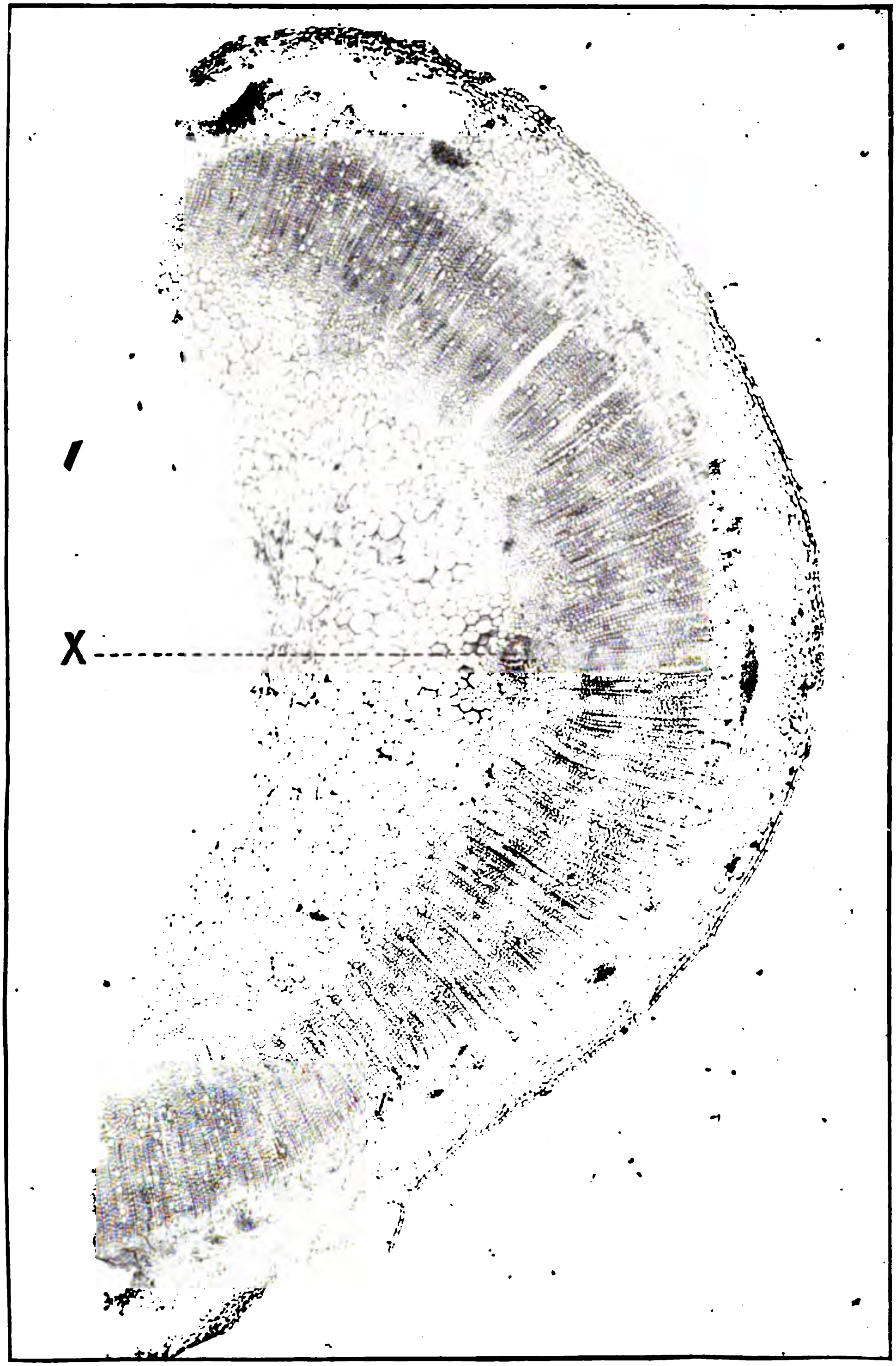


Daisy XVIII. Tumor-strand in petiole A; joins on to Plate LXXIV (p. 46).

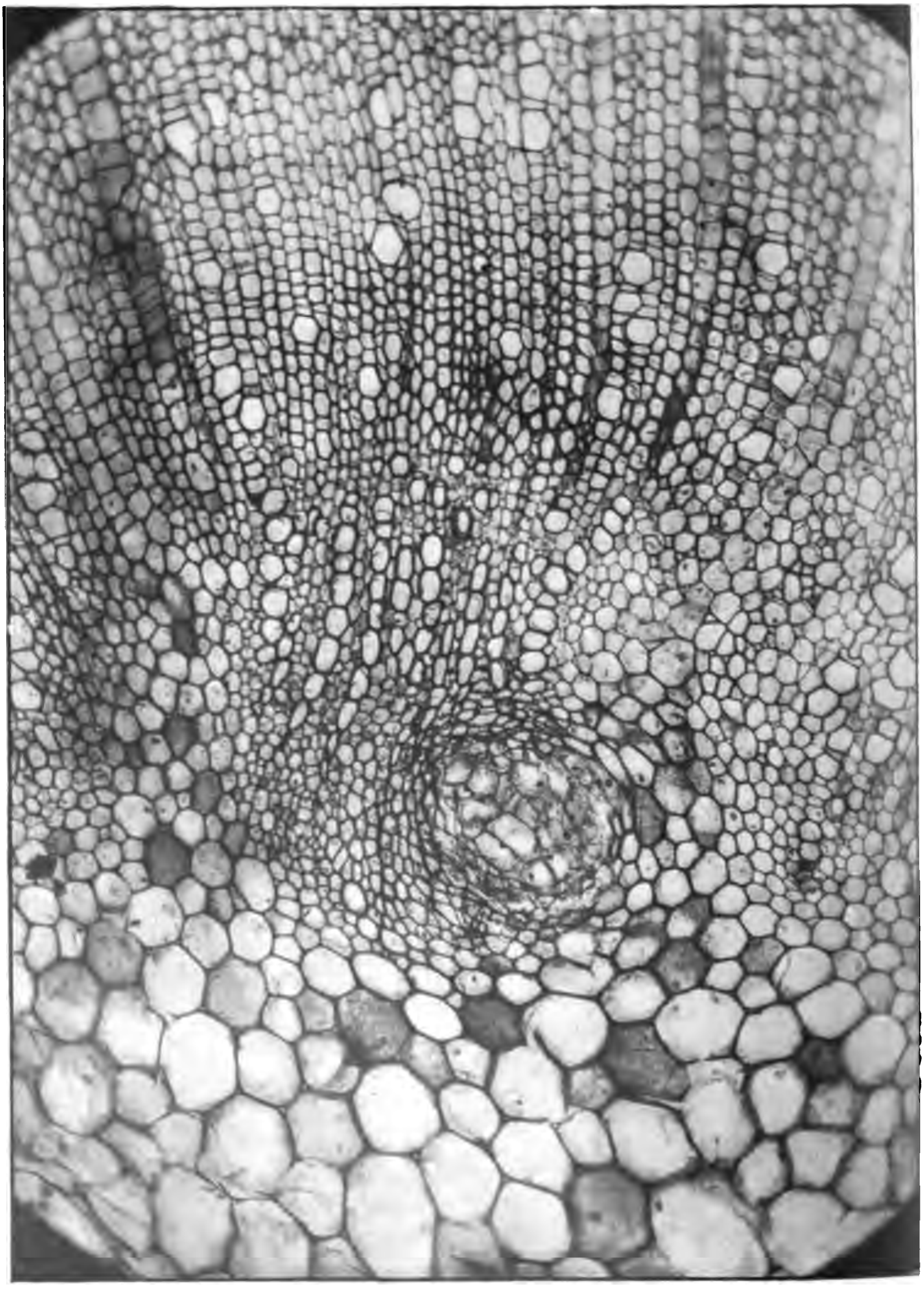
Daisy XVIII. Tumor-strand in petiole A; joins on to Plate LXXV (p. 46).




Daisy XIX. Portion of inoculated plant, showing primary stem tumor and secondary leaf tumors (p. 46).



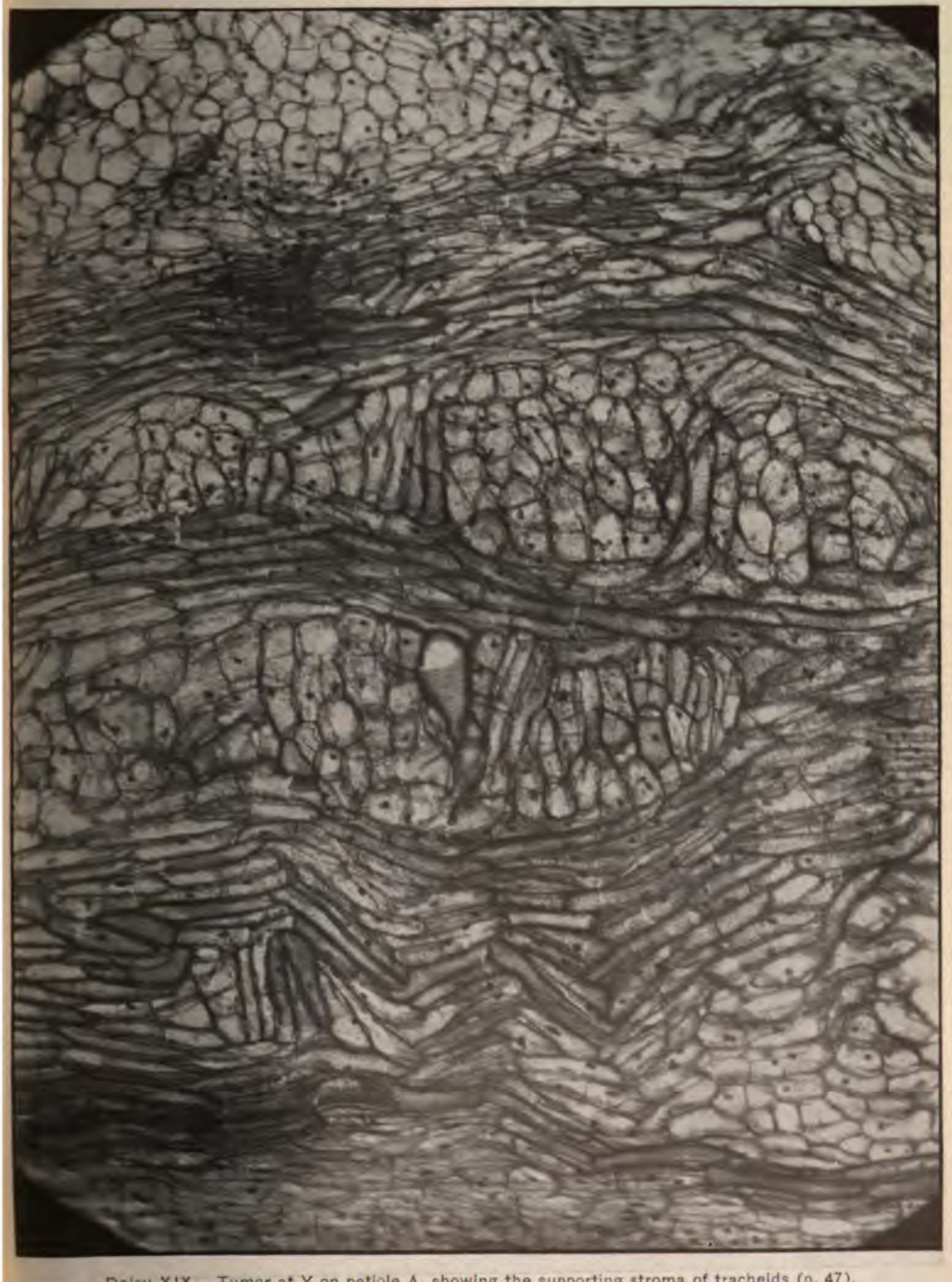

Daisy XIX. Cross section of stem between tumors, showing a tumor-strand at X (p. 46).



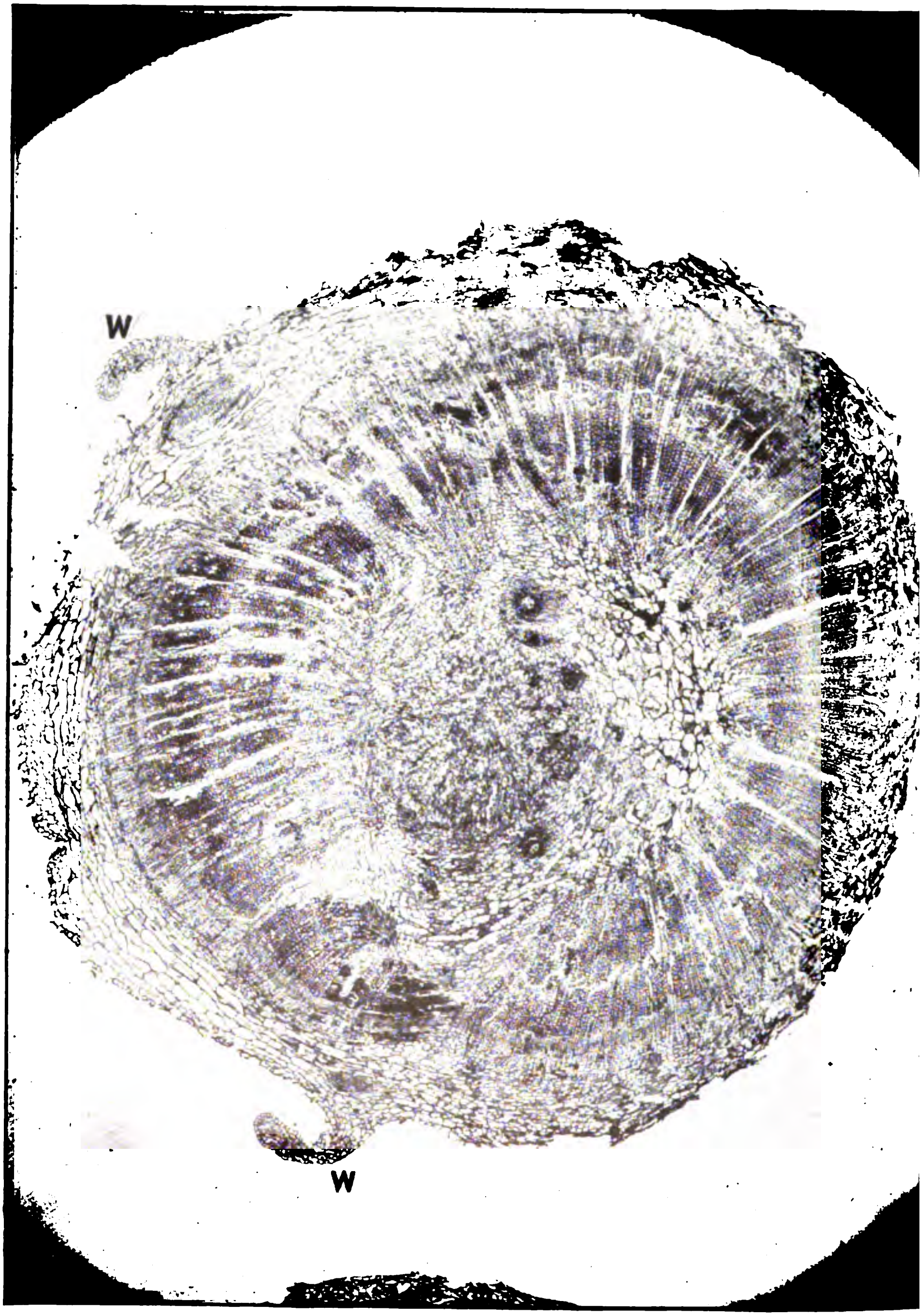
Daisy XIX. A part of Plate LXXVIII, showing tumor-strand region in detail; wood above, pith below (p. 46).

Daisy XIX. Longitudinal section of base of petiole A, showing tumor-strand (p. 47).

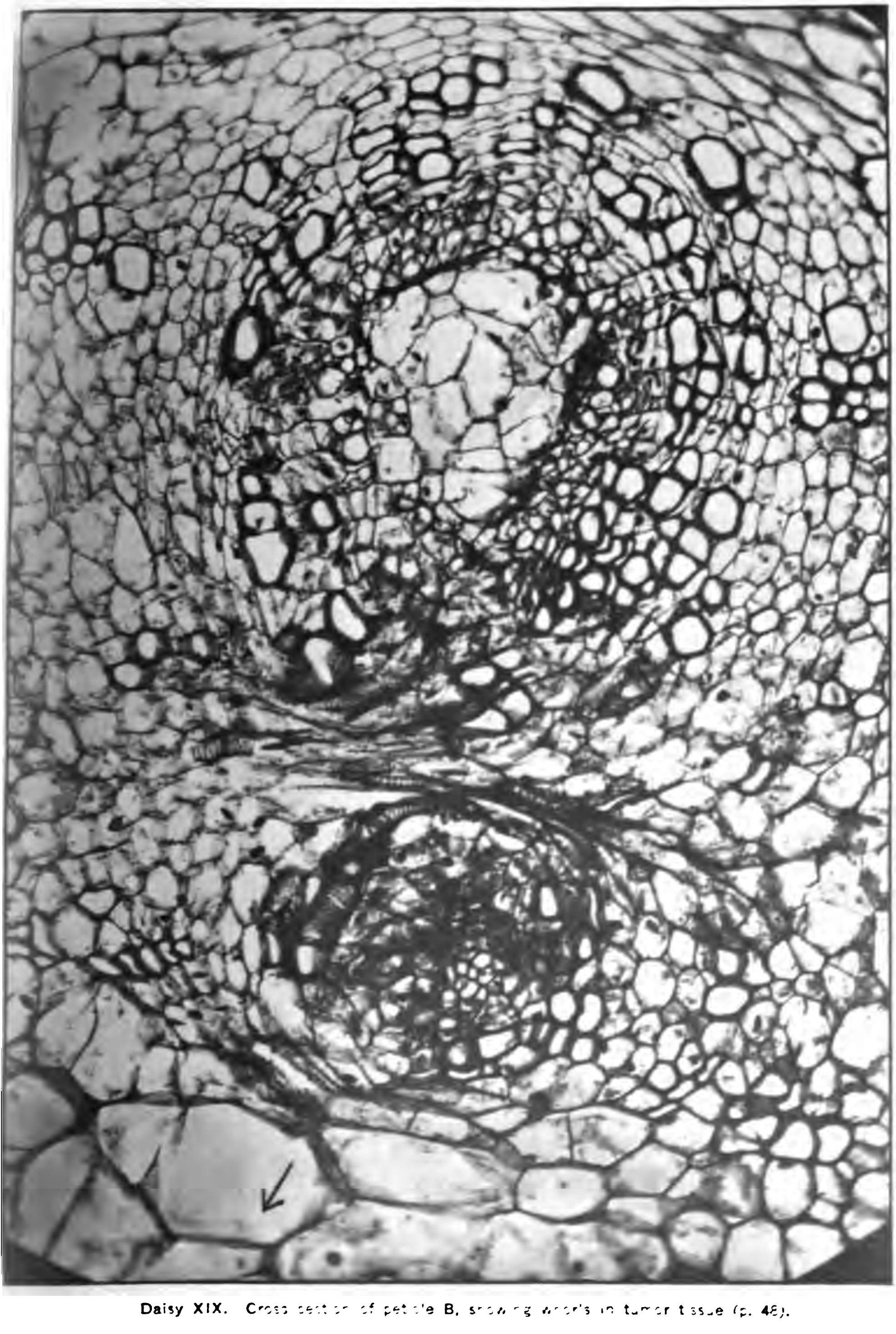

Daisy XIX. Longitudinal section of middle part of petiole A, between tumors (p. 47).



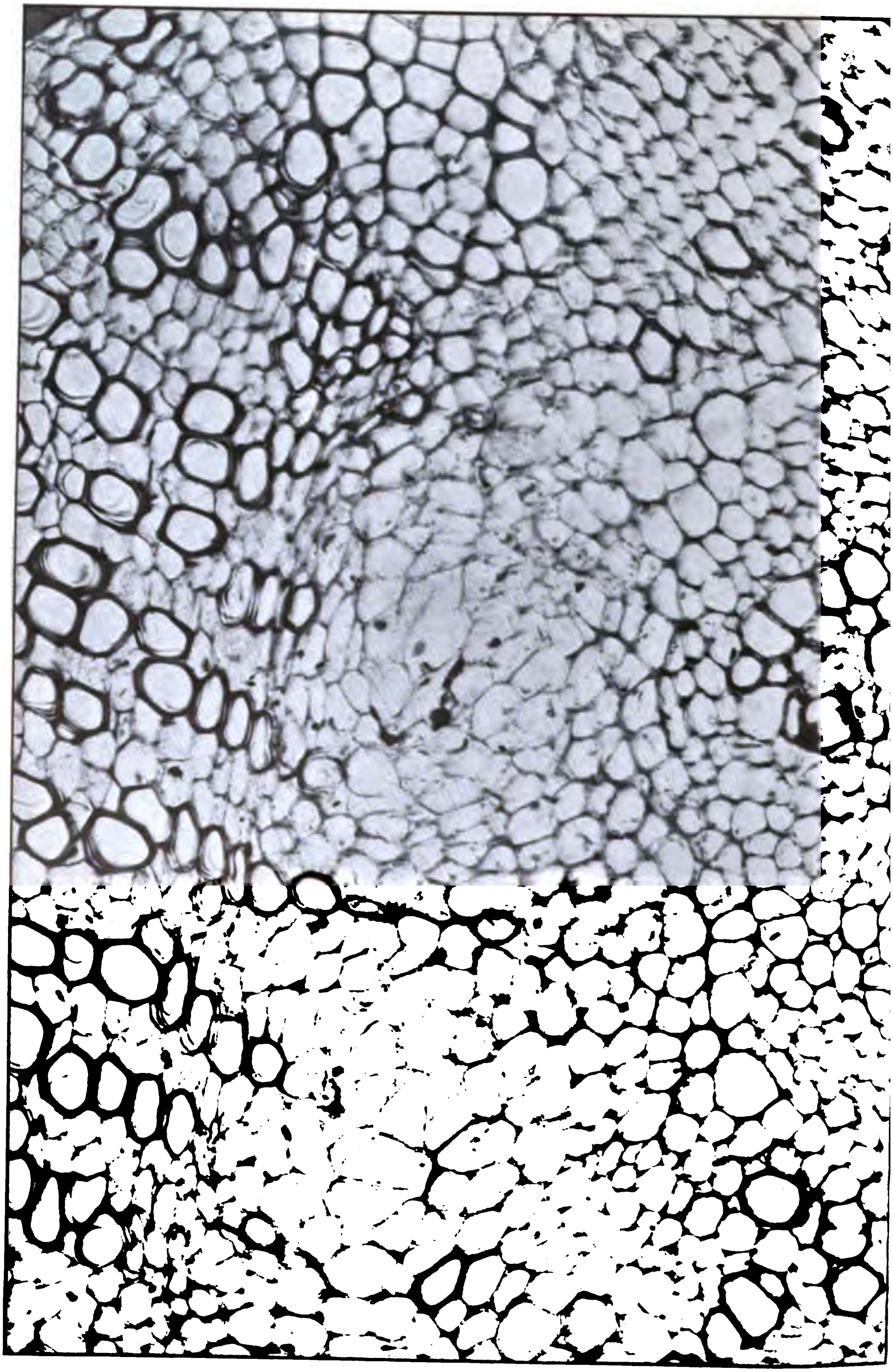
Daisy XIX. Tumor at Y on petiole A, showing the supporting stroma of tracheids (p. 47).



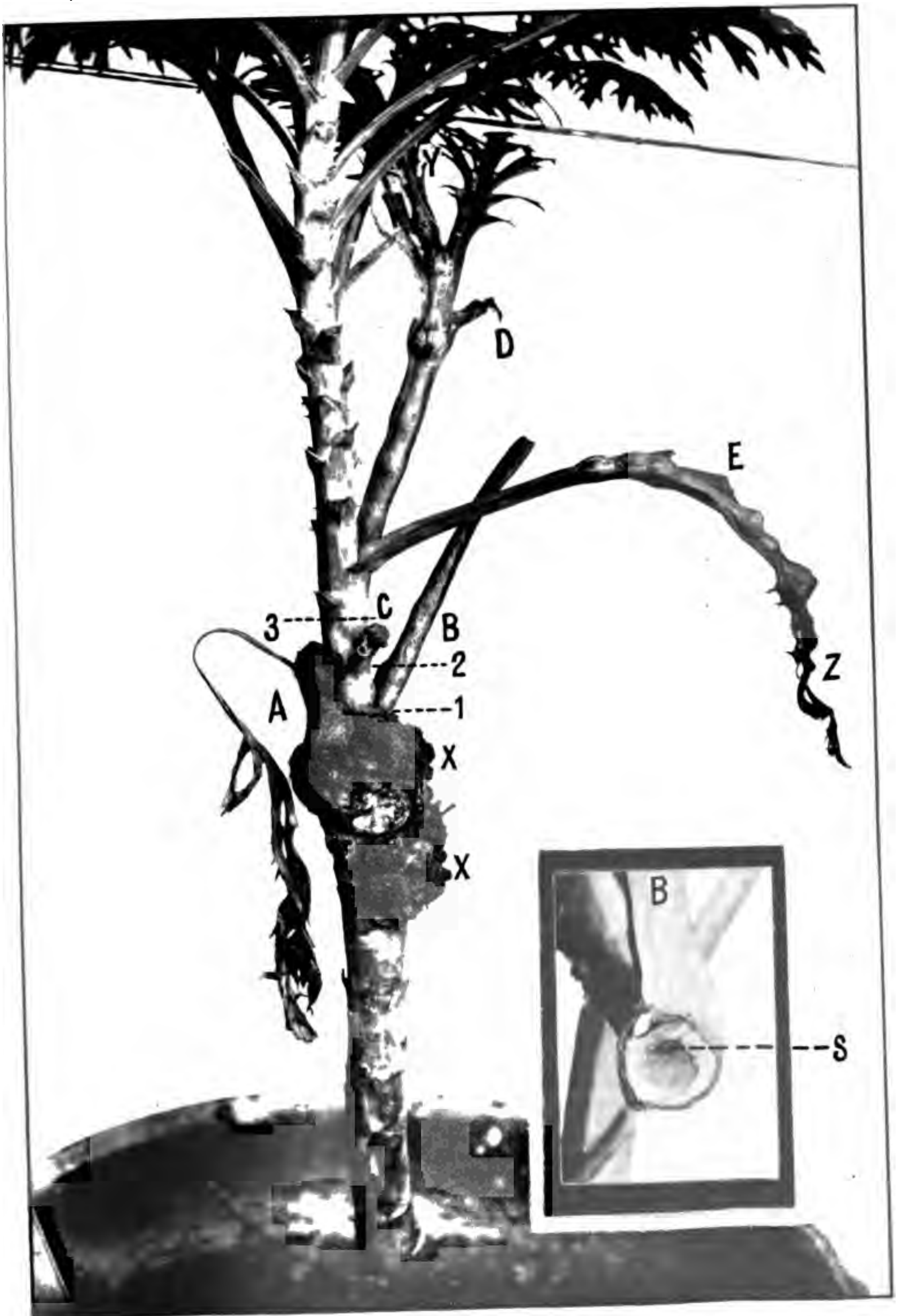

Daisy XIX. Cross section of secondary tumor in petiole B, showing stem structure and coarse-cell inclusions (p. 47).



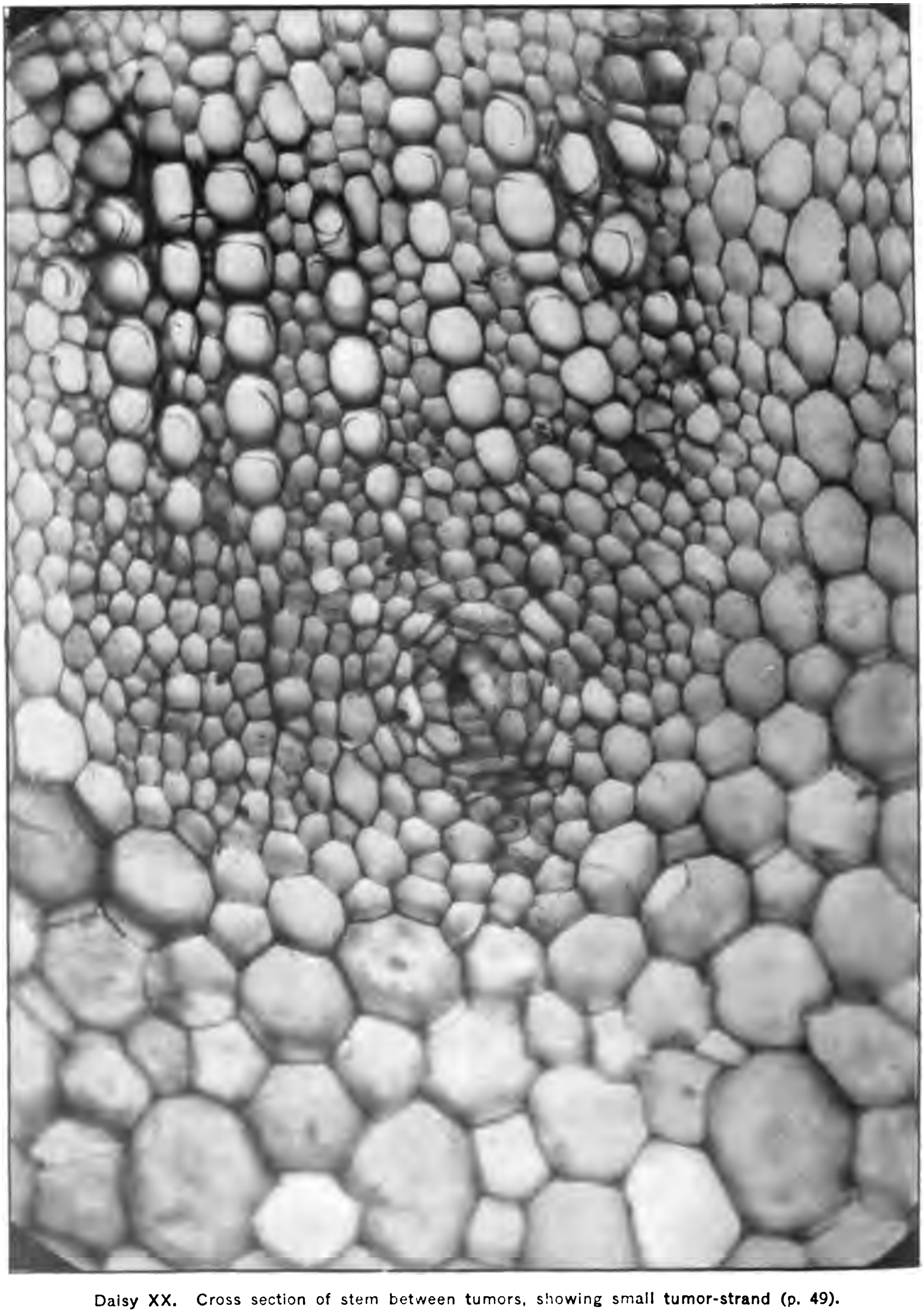
Daisy XIX. Cross section of petiole B, showing whorls in tumor tissue (p. 48).



Daisy XIX. Cross section of base of petiole B in region of tumor-strand (p. 48).



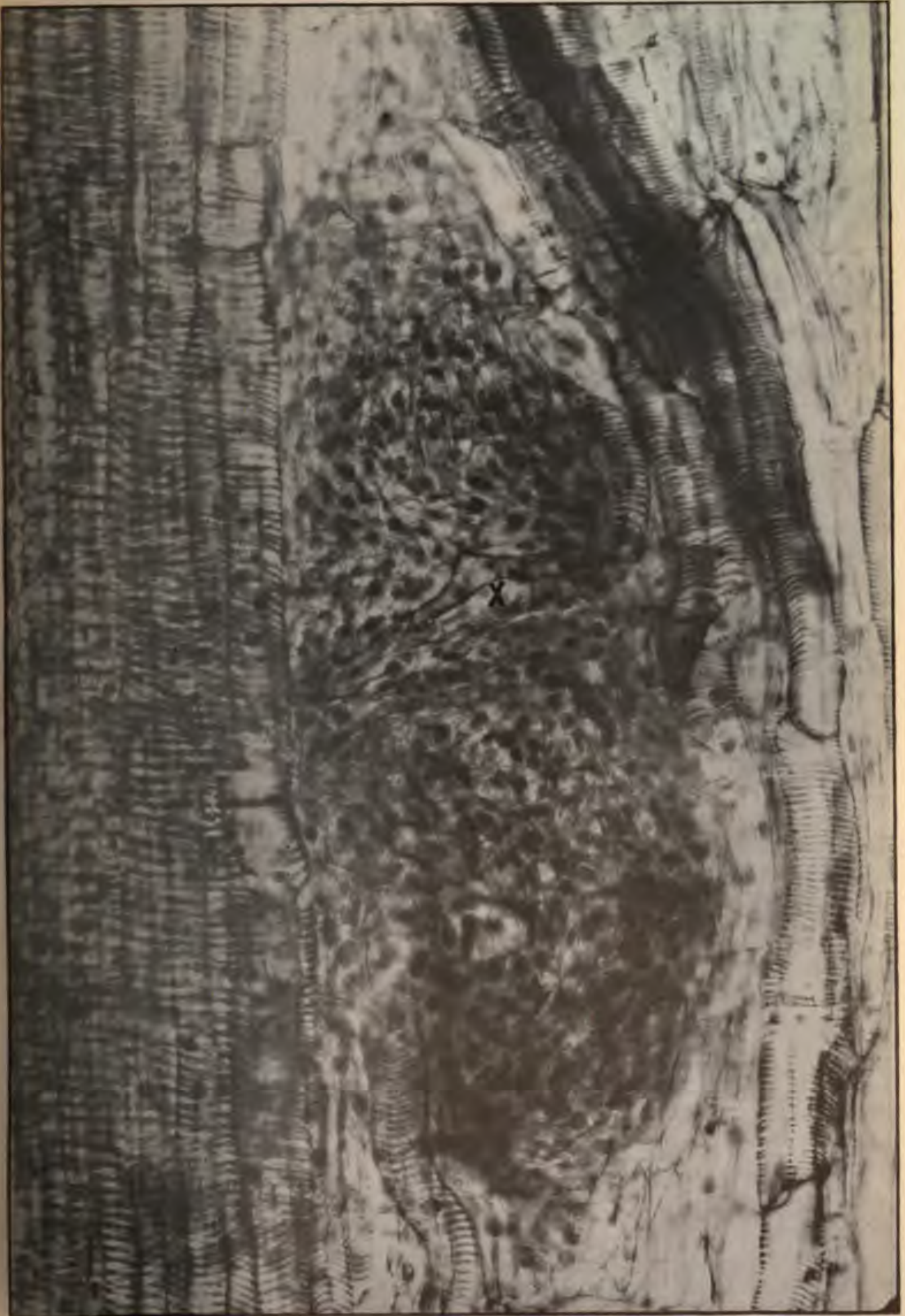

Daisy XX. Primary stem tumor and secondary leaf tumors; also a cross section of stem at 1 (p. 48).



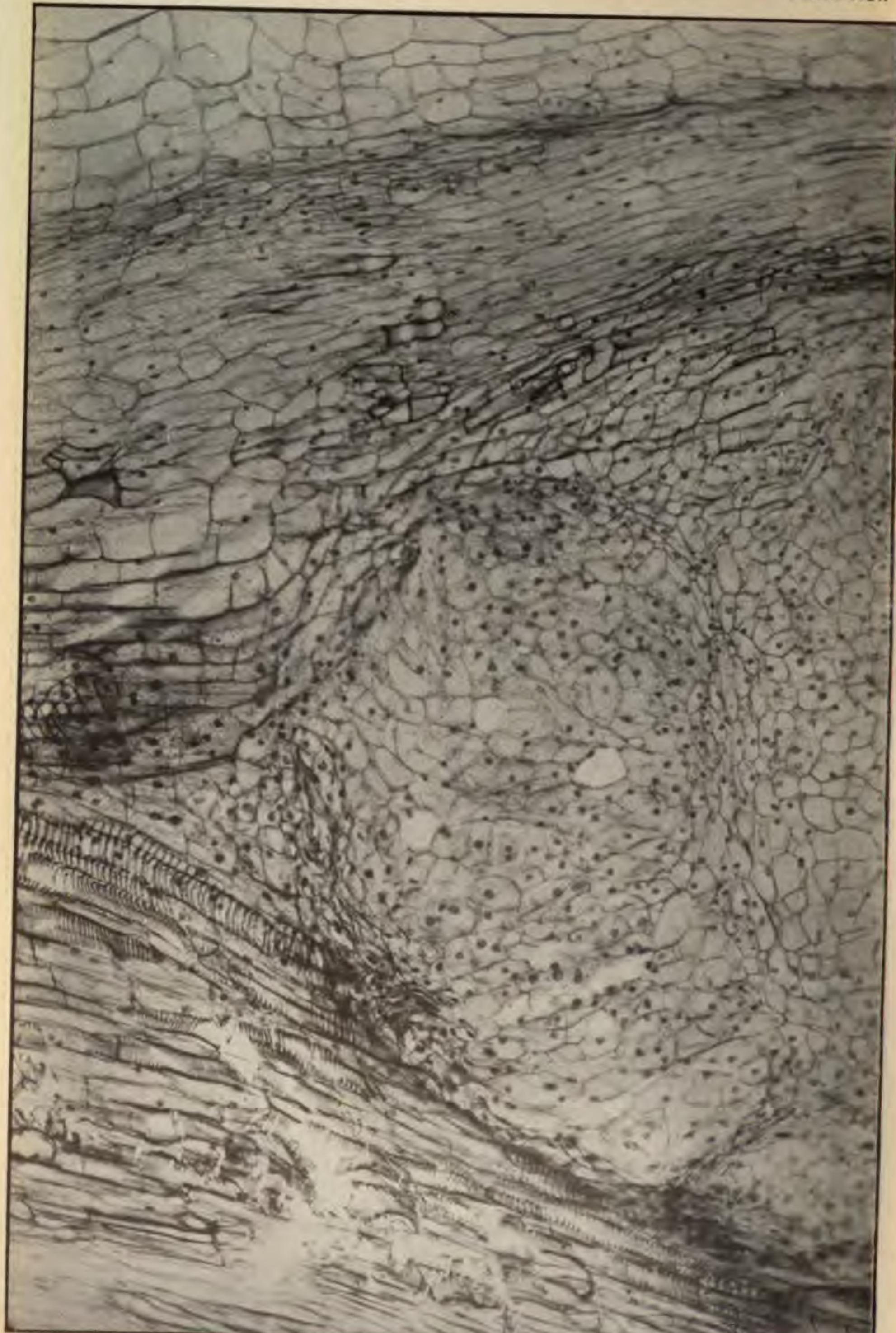
Daisy XX. Cross section of stem between tumors, showing small tumor-strand (p. 49).

Daisy XX. Longitudinal section of petiole D, showing a young neoplasm (p. 49).

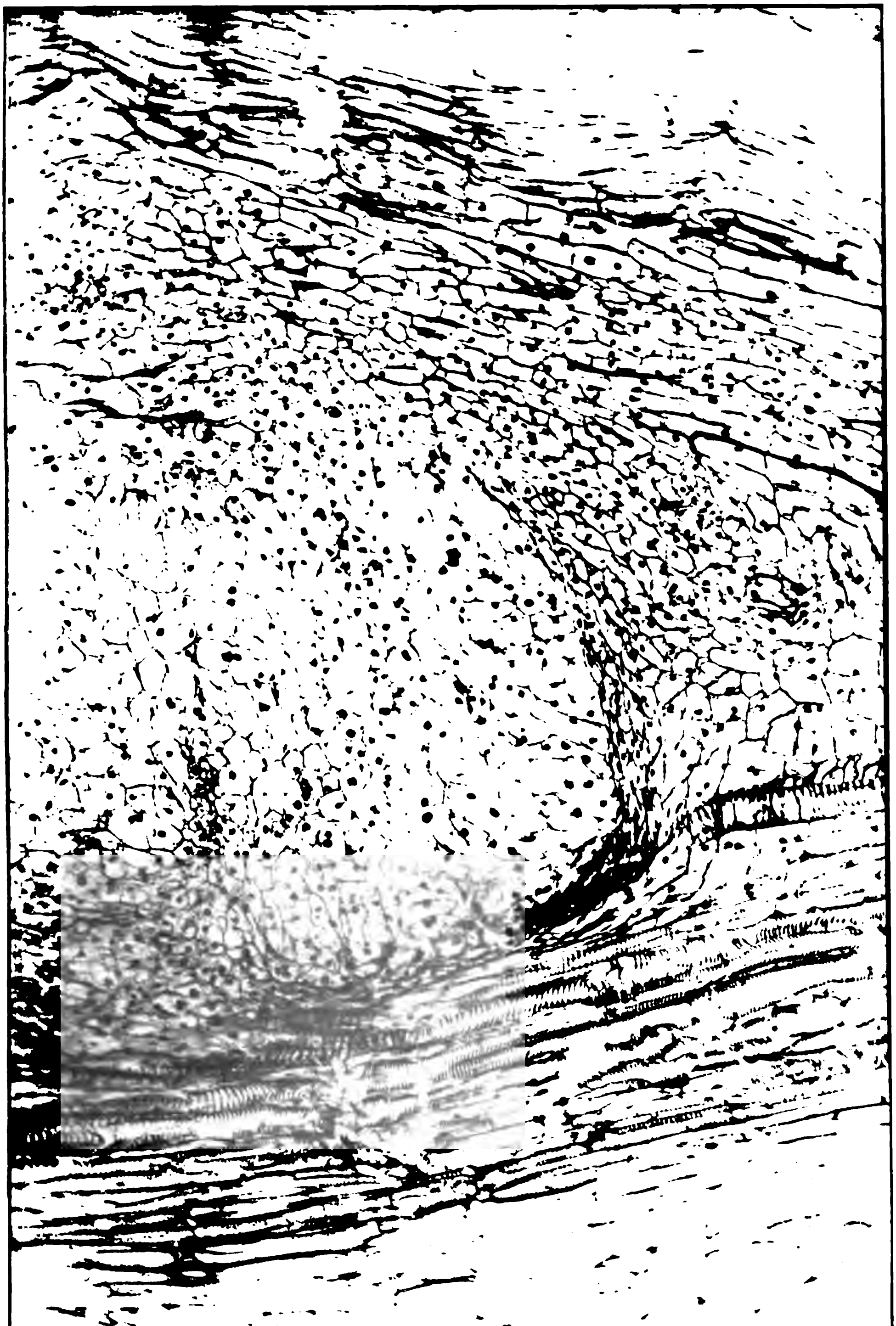
Daisy XX. Upper end of small neoplasm shown on Plate LXXXVIII (p. 49).




Daisy XX. Margin of small neoplasm, showing spirals wedged apart, and abnormal tracheids at X (p. 49).

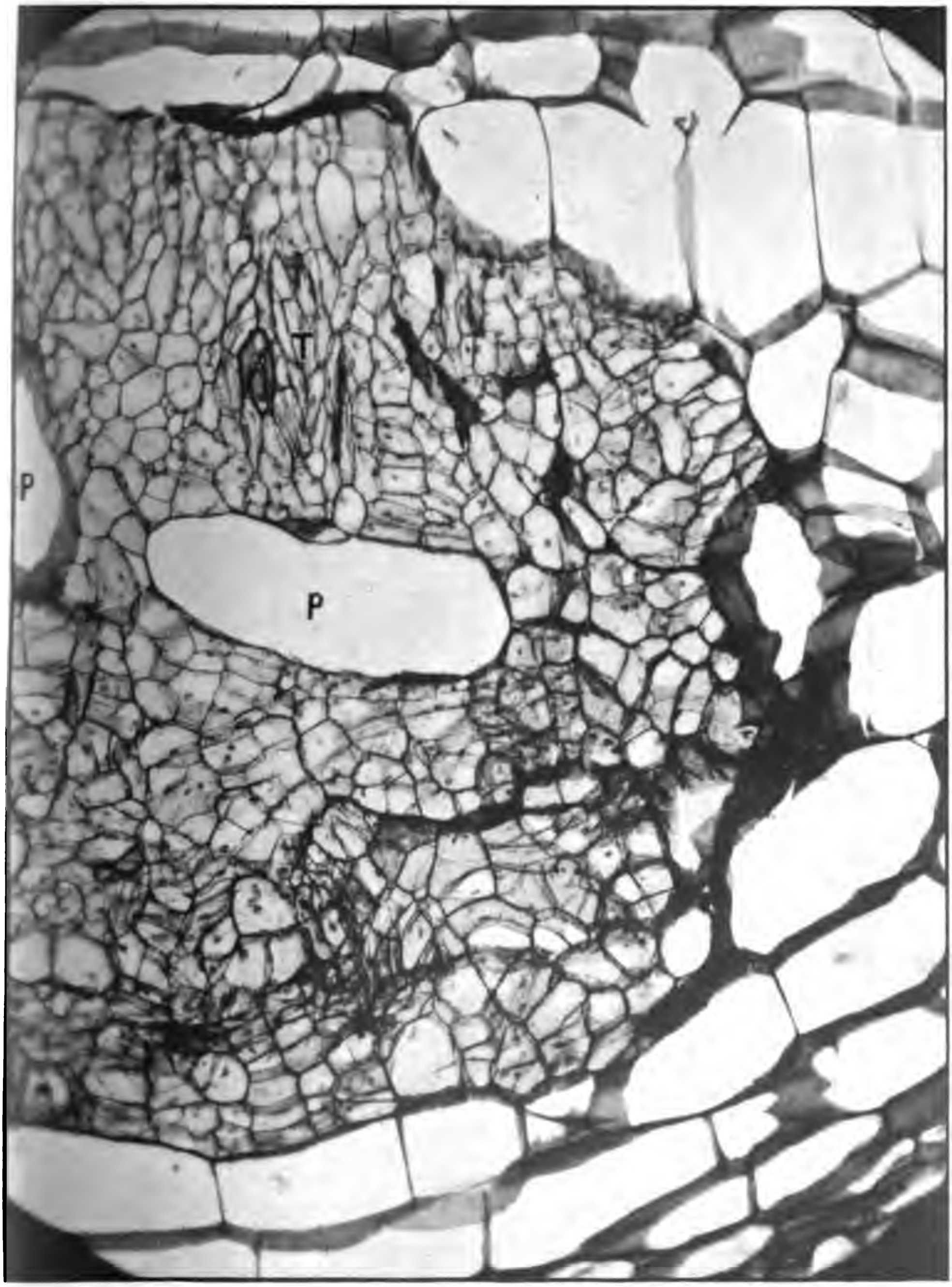


Daisy XX. One end of small unruptured tumor in petiole D (p. 49).



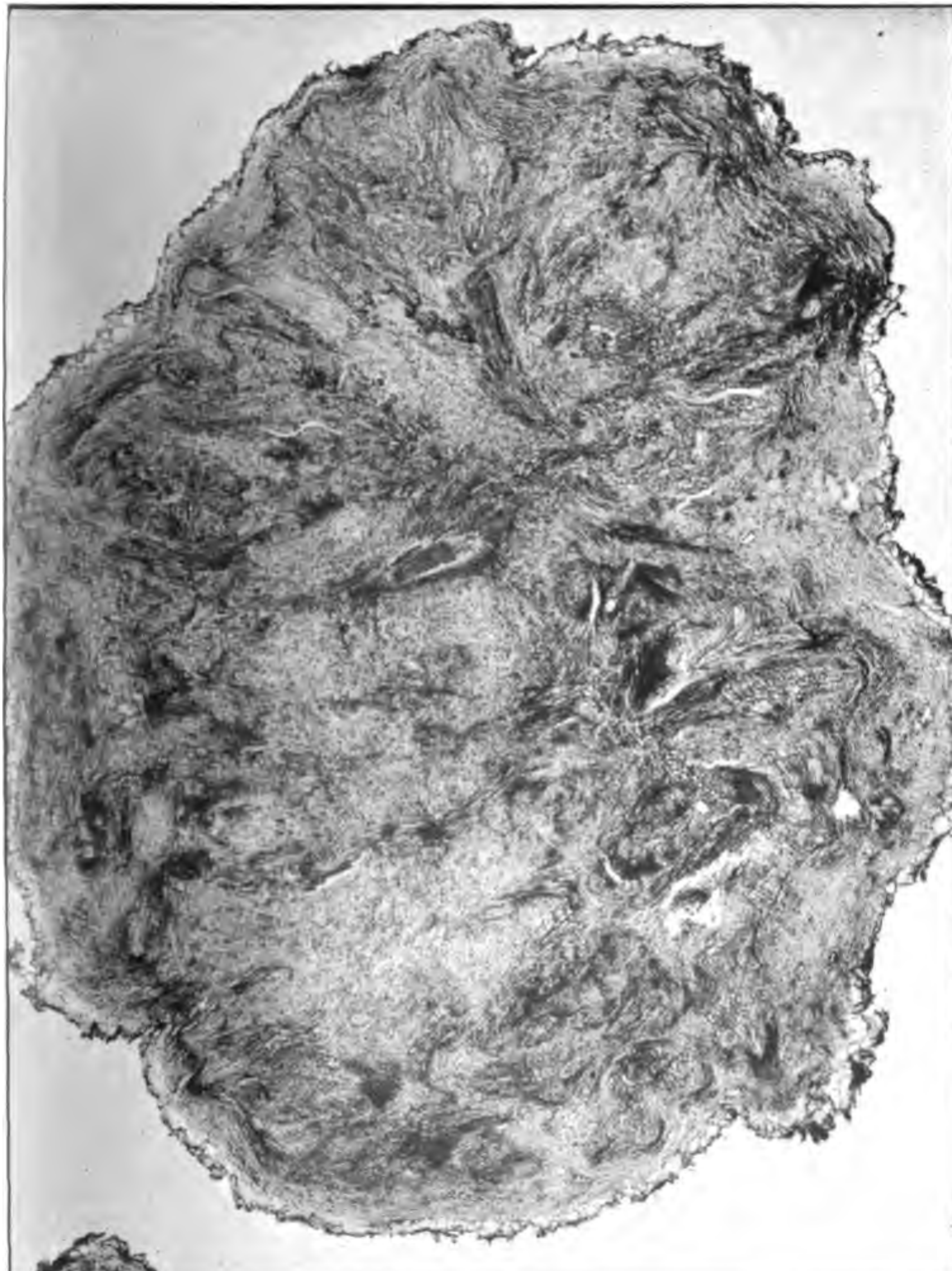
Daisy XX. Same as Plate XCI, but from the other end of the tumor (p. 49).

Daisy XX. Continuation of tumor-strand in petiole D (p. 50).



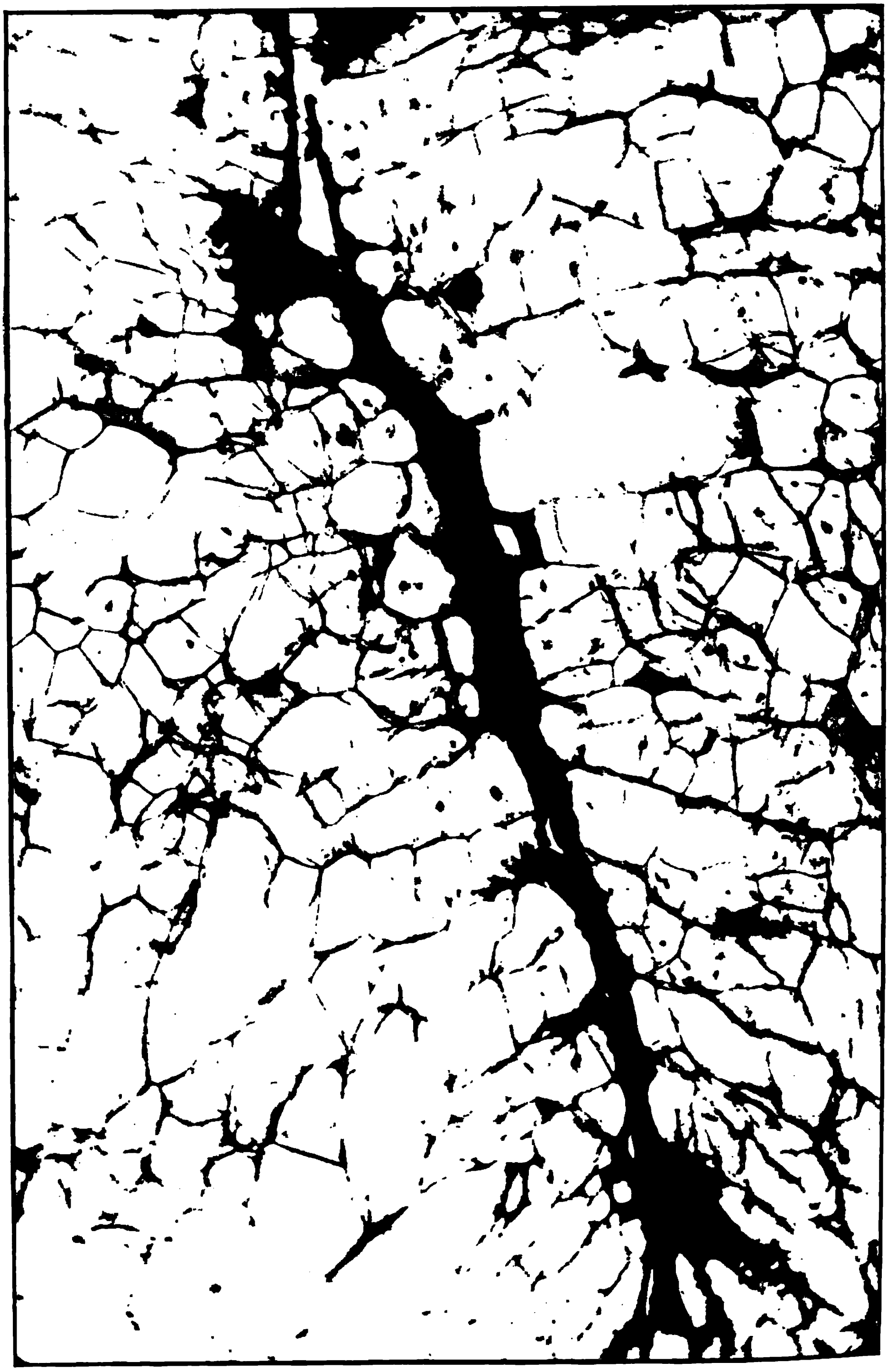

Daisy.—Margin of a tumor in a leaf stalk, showing tracheids at T, and inclusions of petiole parenchyma at P; at the right, ordinary ground tissue of the petiole (p. 50).

Daisy XXXI. Primary tumors on leaves (p. 50) resulting from single needle-prick inoculations introducing Bacterium tumefaciens. These galls do not have stem structure. For details, see next plates.

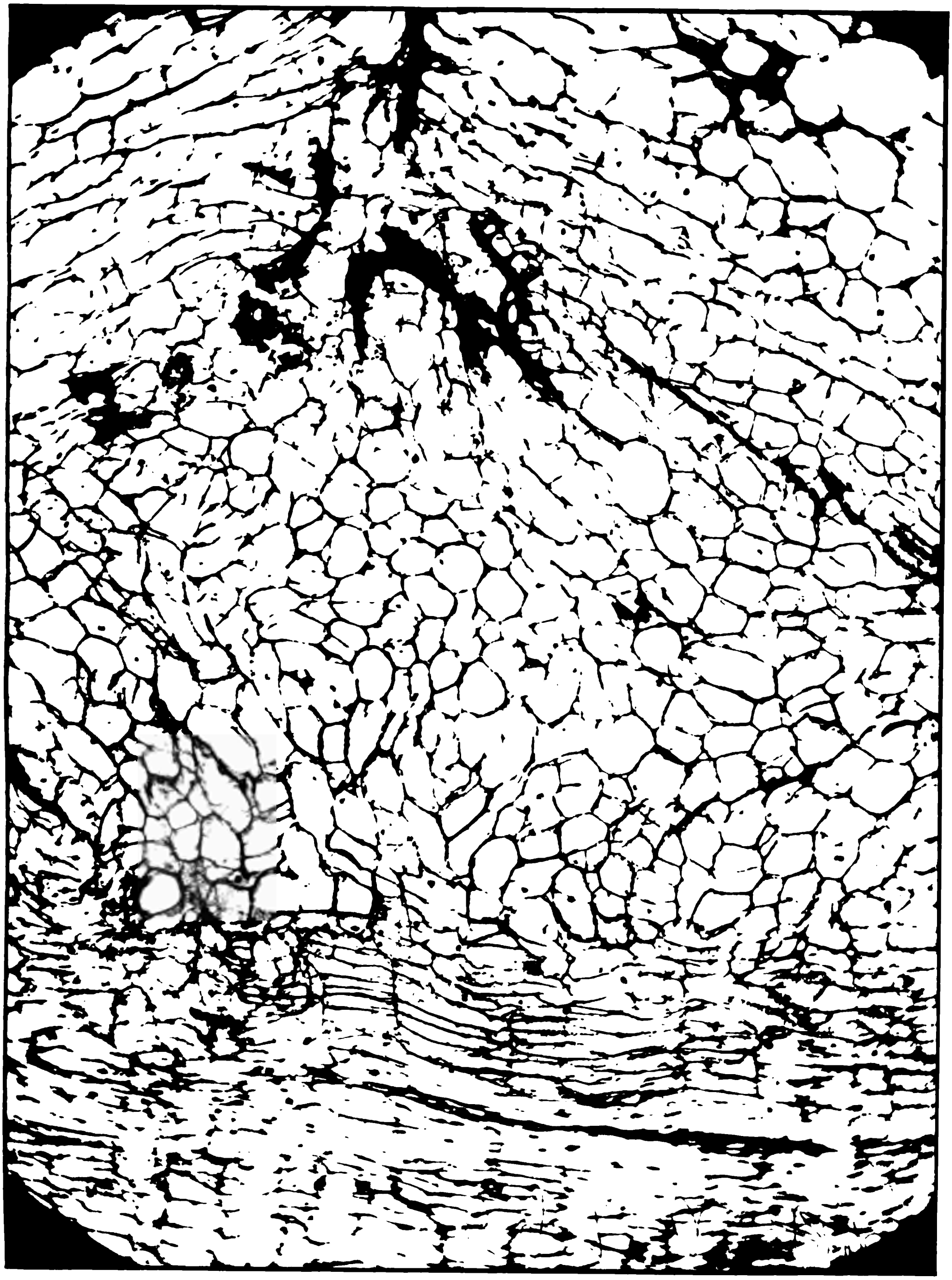


Daisy XXXI. Cross section of a primary leaf-tumor, for comparison with any of the secondary leaf-tumors, e. g., Plate LV. The numerous minute dots are deep-staining nuclei (p. 50).

Daisy XXXI. Vertical section of another primary leaf tumor; normal part at the left (p. 50).

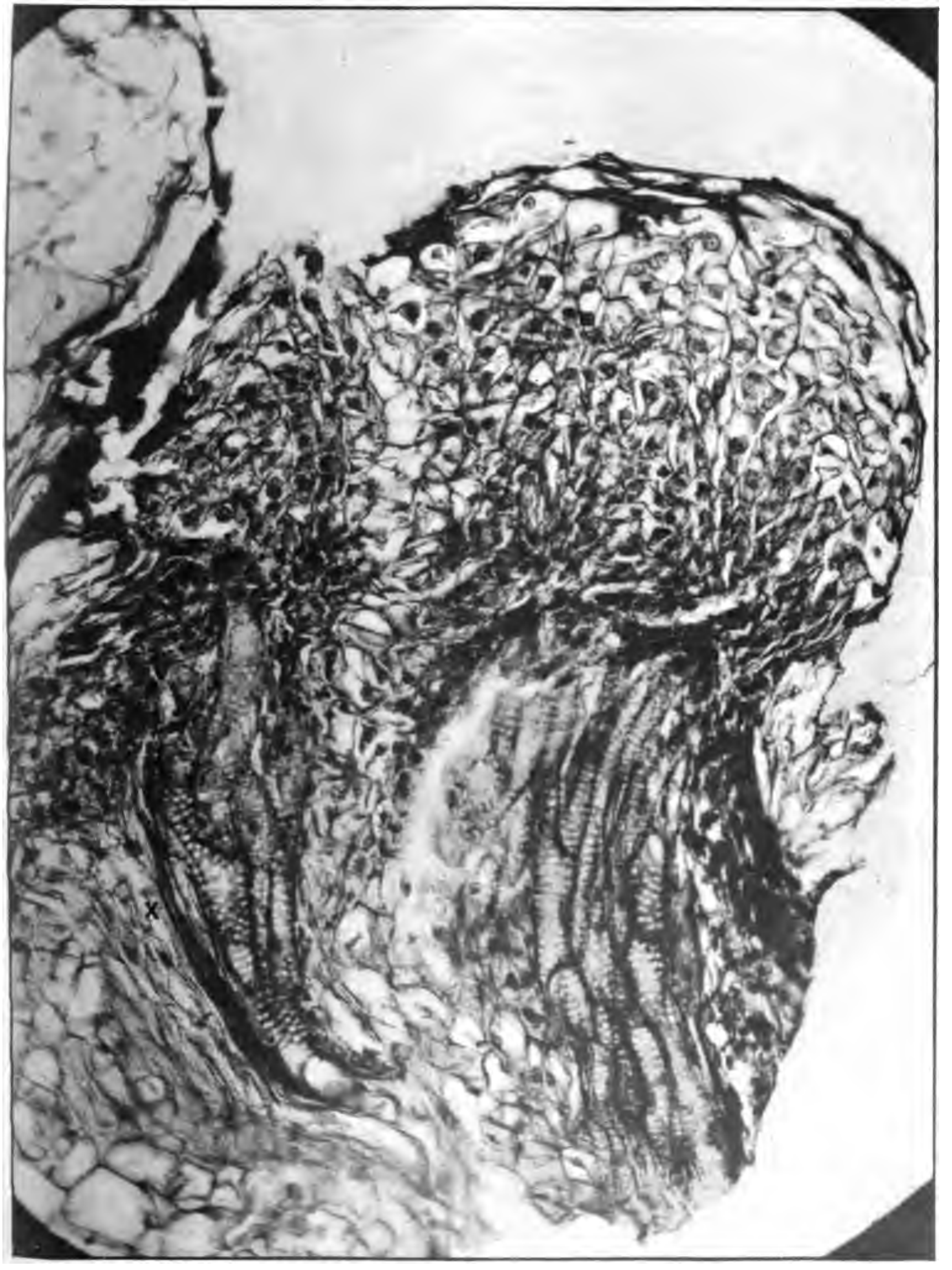


Tobacco. Infected needle-track through pith; no proliferation (p. 50).



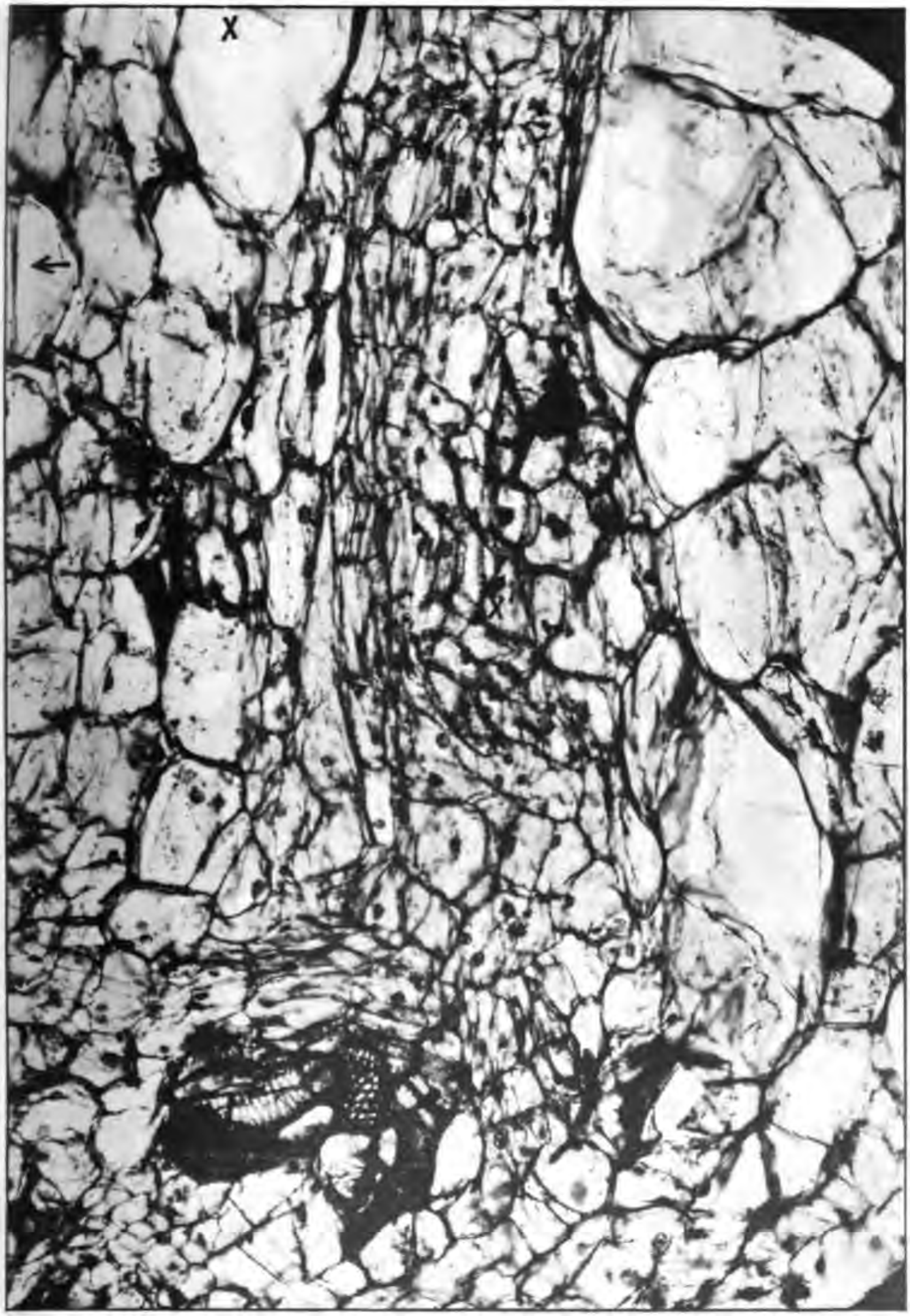
Tobacco. Longitudinal radial section, showing infected needle-track in cambium region with cells proliferating (p. 51). Time, 3 weeks.


Tobacco. Margin of infected needle wound, showing tumor at top (p. 51).

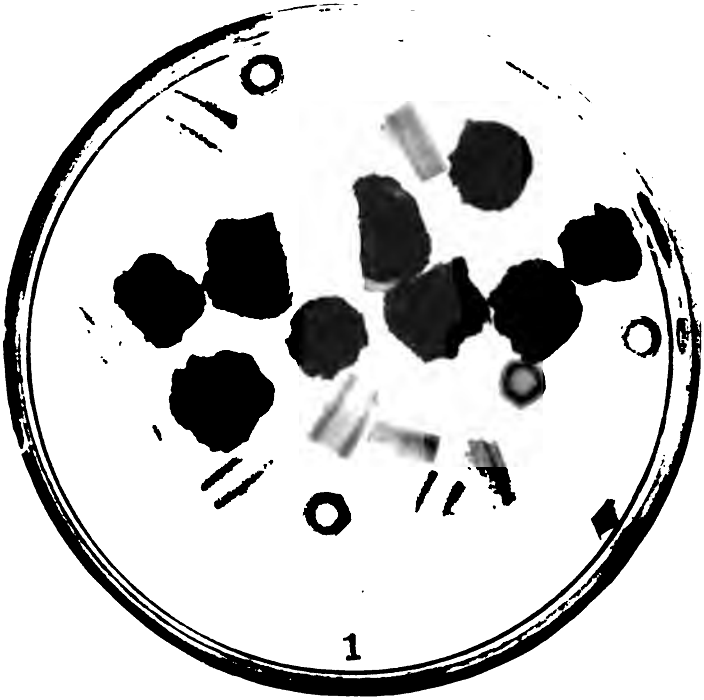



Tobacco. Margin of infected needle wound. Tumor in middle part of bark parenchyma; sieve tubes at X (p. 51).


Tobacco. Tumor-strand in cortical parenchyma. Bottom joins top of next plate (p. 51).




Tobacco. Tumor-strand with tracheids in cortical parenchyma (p. 51).



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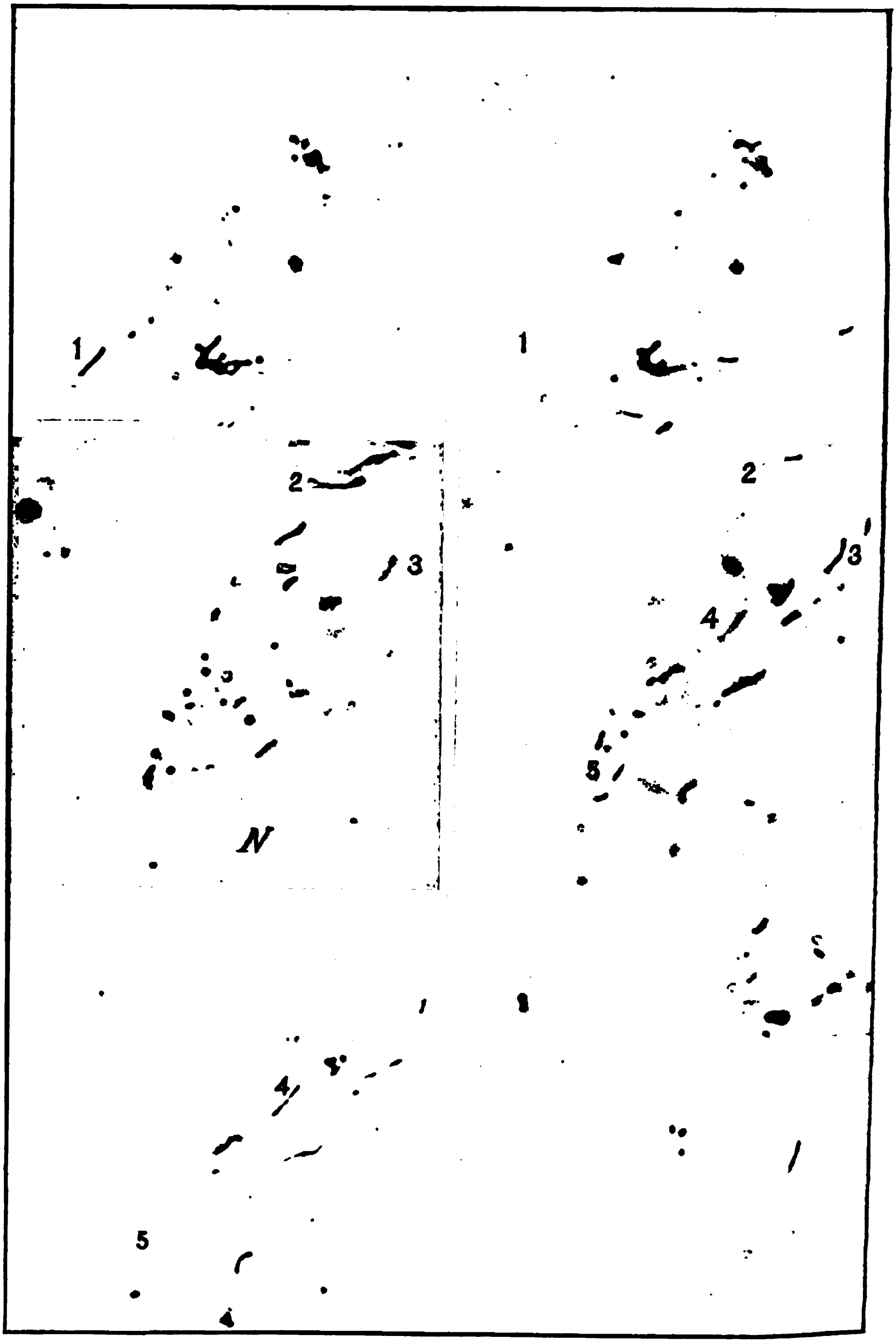
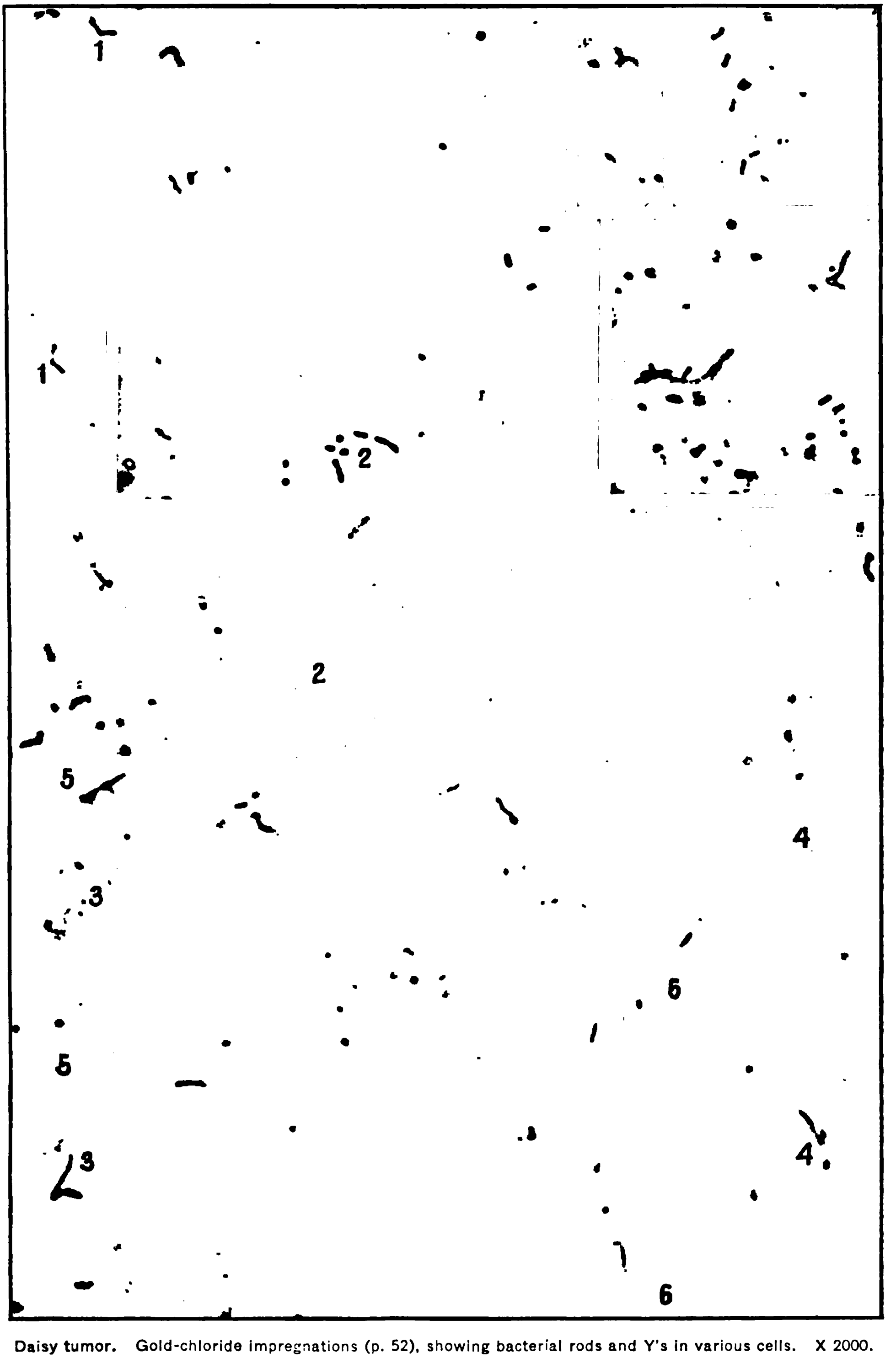
Daisy tumor. Reaction with chromium salts (pp. 23 and 51).

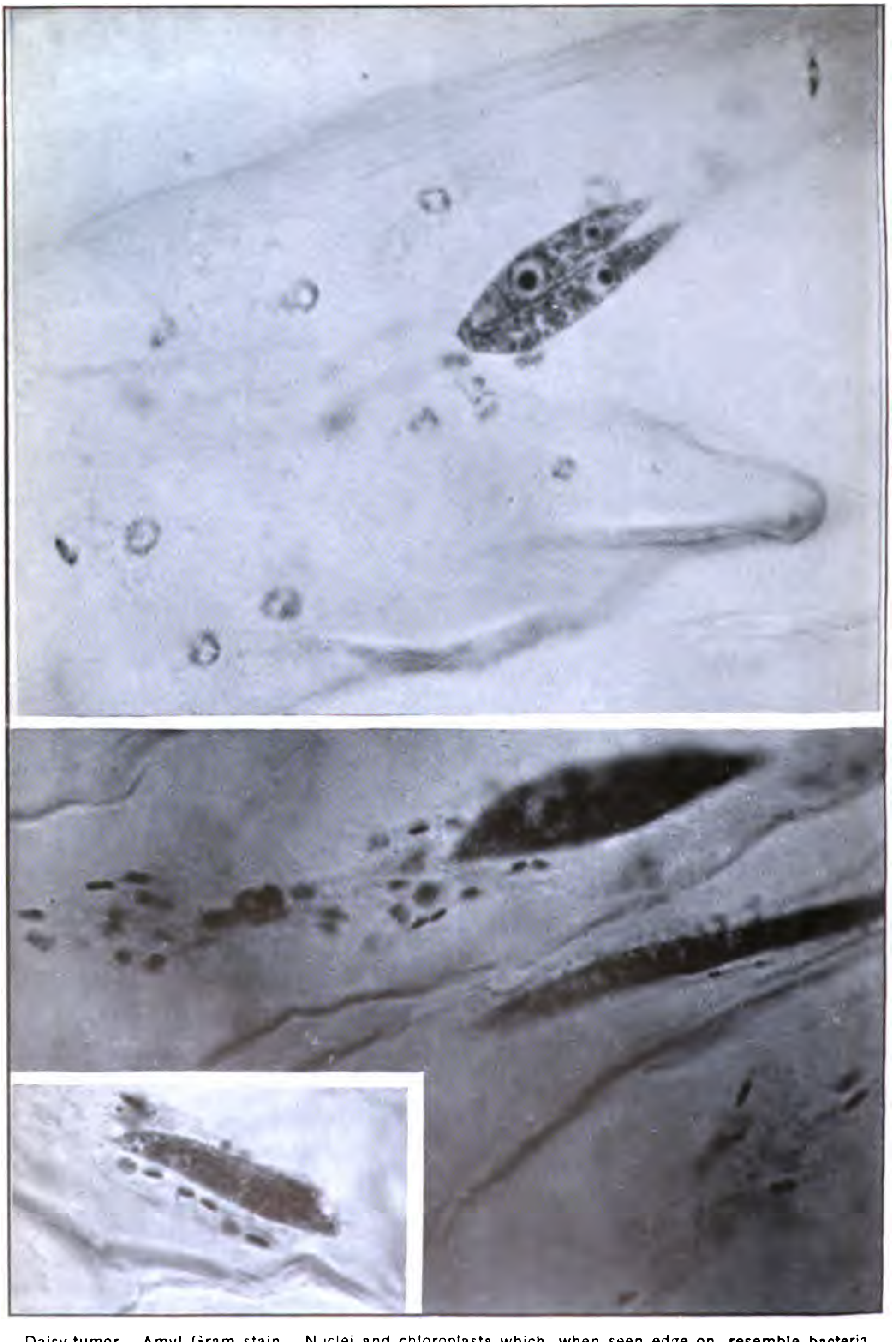

Daisy tumor. Gold-chloride impregnations (p. 52), showing bacterial rods and Y-bodies within the cells. X 2000.



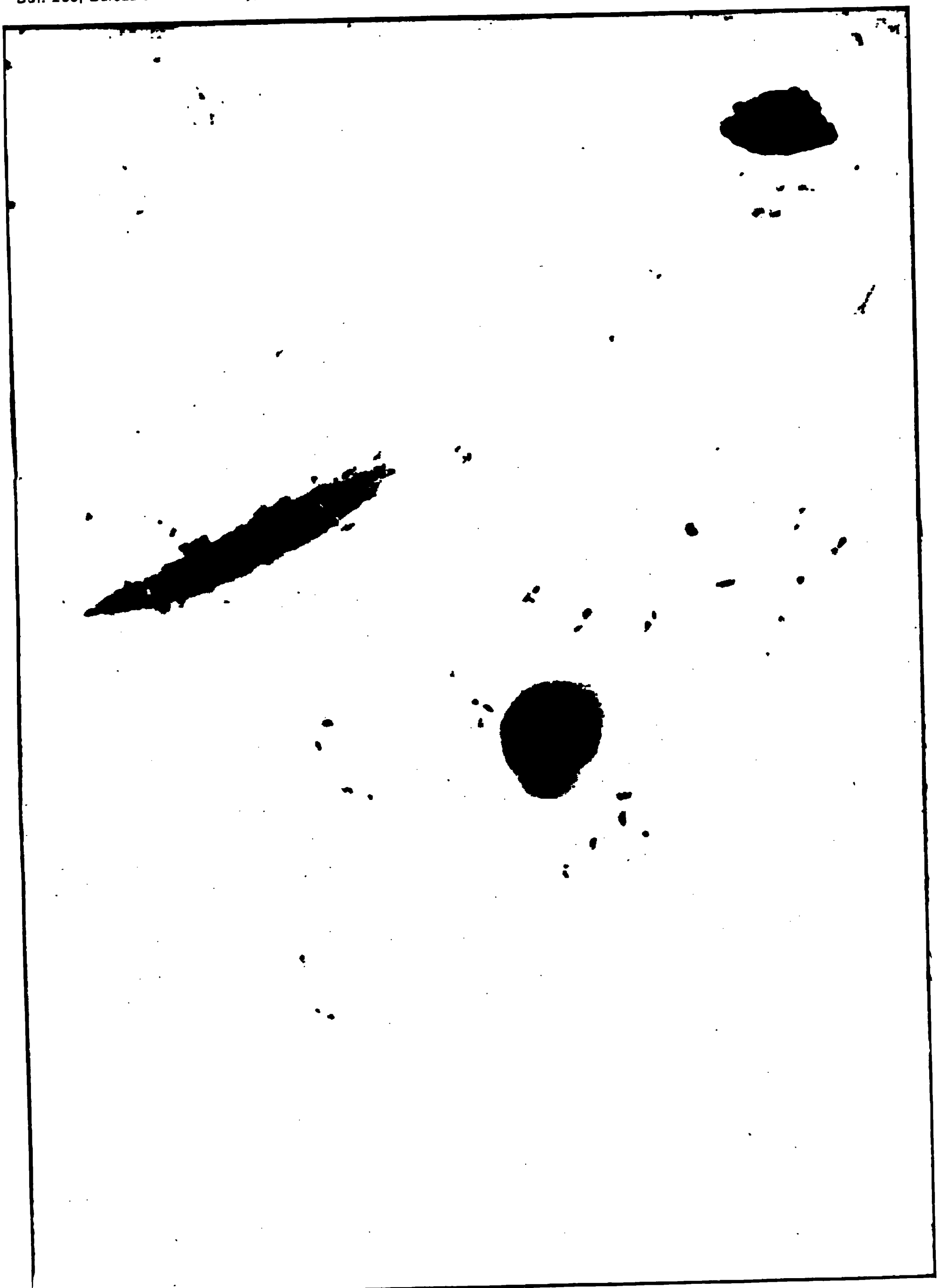

Daisy tumor. Gold-chloride impregnations (pp. 18, 19, 52), showing eight levels in a cell containing bacterial rods. X 2000.




Daisy tumor. Gold-chloride impregnations (p. 52), showing bacterial rods and Y's in various cells. X 2000.



Daisy tumor. Amyl Gram stain. Nuclei and chloroplasts which, when seen edge on, resemble bacteria (pp. 19 and 53). Upper nucleus dividing amitotically. X 2000.



Daisy tumor. Amyl Gram stain over washed, showing nuclei and rod-shaped bodies believed to be normal constituents of the cell (p. 53). The lower nucleus out of focus in order to make the other bodies distinct. X 2000.

Issued January 18, 1913.

U. S. DEPARTMENT OF AGRICULTURE.

**BUREAU OF PLANT INDUSTRY—BULLETIN NO. 256.**

B. T. GALLOWAY, *Chief of Bureau.*

# HEREDITY AND COTTON BREEDING.

BY

O. F. COOK,

*Bionomist in Charge of Crop Acclimatization and Adaptation Investigations.*

WASHINGTON:

GOVERNMENT PRINTING OFFICE.

1913.

## BUREAU OF PLANT INDUSTRY.

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# LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Plant Industry,
Office of the Chief,
*Washington, D. C., May 25, 1912.*

Sir: I have the honor to transmit herewith a paper entitled "Heredity and Cotton Breeding," by Mr. O. F. Cook, Bionomist in Charge of Crop Acclimatization and Adaptation Investigations, and to recommend its publication as Bulletin No. 256 of the bureau series.

This paper outlines some new methods and standpoints for the study of heredity, with applications to practical problems in the breeding of cotton. It shows how problems of heredity and methods of breeding can be simplified by a more definite recognition of the fact that the expression of characters is distinct from transmission. In addition to these general results detailed information is given regarding the habits of the various types of cotton, the effects of external conditions, and the behavior of the different characters in heredity.

In addition to its use by other investigators and breeders, a general paper of this kind should render the subject of cotton breeding more interesting from the educational standpoint and assist extension workers in understanding and presenting to the farmer the reasons for the improved methods of selection that have been developed. Though the paper necessarily deals with scientific distinctions, technical terms are employed only when the meanings are explained by definitions or by reference to familiar facts.

Very respectfully,

B. T. Galloway,
*Chief of Bureau.*

Hon. James Wilson,
*Secretary of Agriculture.*

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# HEREDITY AND COTTON BREEDING.

## INTRODUCTION.

The breeding of new varieties is no more difficult with cotton than with other plants, but the relation of heredity to the cotton crop does not end with the breeding of varieties. To preserve a superior variety so that it can be utilized for purposes of production is a more difficult practical problem than the breeding of a new variety, and requires an equally intimate acquaintance with the facts of heredity. On account of the industrial uses of the cotton fiber, uniformity is of much greater importance than with other field crops, but methods that secure uniformity in other crops are not applicable to cotton. The habits of the plant and the unorganized state of the industry seem to preclude the establishment of any centralized system of seed production.

The improvement of the cotton industry through the utilization of superior varieties is likely to require a large development of popular interest in the applications of heredity to cotton production. The methods of scientific agriculture are much more likely to secure effective application among those who understand the underlying facts that make such methods necessary. The farmer who undertakes to follow directions without understanding the reasons for them is likely to make but poor and ineffective use of any method that requires special care or skill.

The intelligent farmer has not only a material advantage to gain but also a much greater interest and satisfaction in his work, if he learns the reasons for what he is doing and is able to place a correct interpretation upon the characters and behavior of the plants that engage his attention. It is true that a special training is necessary for effective work in breeding and selection, in the sense that detailed knowledge is required, but it is a training that can be secured on the farm better than anywhere else. Moreover, the cotton plant affords unusual opportunities for gaining insight into the problems of heredity and breeding. Many of the complicated methods used on other plants by laboratory workers and statistical biologists are unnecessary with cotton, for reasons that are explained in this bulletin.

Direct, practical familiarity with the fact of heredity in such a plant as cotton is a much more effective training in plant breeding than any that the school can supply through the medium of formal instruction. The farmer who learns how to select his own cotton not only makes his crop more profitable but has something of real value to teach his children. In spite of the general tendency to assume that everything in the way of detailed knowledge must be learned in school, the educational possibilities of farm life are beginning to be appreciated. The development of a truly agricultural civilization will be assured when people understand that farm life has larger possibilities of human development than urban existence. Genuine farm education is needed—not merely agricultural courses in schools.

It is not expected that this bulletin can be made generally available for the purpose of home instruction in cotton breeding, nor is it intended for this purpose. Such a manual, containing detailed accounts of the characters and habits of the varieties, might be useful in educational work but is not yet available. The best way to become familiar with a variety of cotton is to study it in the field. Such study is facilitated by having a general point of view for understanding the facts, even more than by being told in advance exactly what should be seen. This bulletin states the general biological reasons for the methods of breeding and selection that have been suggested in previous publications of the Bureau of Plant Industry.[1]

A recognition of the general relations of heredity to cotton breeding is the first requisite for placing the subject on an adequate scientific basis. The real task of agricultural investigators, experiment station workers, and other agencies enlisted in the improvement of the cotton industry is the education of the cotton-growing public, so that better cotton can be grown. But the experts must first understand the problem, if their teaching is to benefit the public.

It is not safe to prescribe methods of cotton breeding merely on a basis of analogy with other crops. The methods developed for cereals and other self-fertilized plants are not adequate. A much wider range of biological facts must be taken into account in the breeding and selection of open-fertilized plants like cotton. Indeed, the problem of preserving and utilizing superior varieties of cotton has important economic and educational aspects, for it can not be solved by the individual farmer working alone, but requires the organization of cotton-growing communities devoted to the produc-

[1] Local Adjustment of Cotton Varieties, Bulletin 159, Bureau of Plant Industry, U. S. Dept. of Agriculture, 1909. Cotton Selection on the Farm by the Characters of the Stalks, Leaves, and Bolls, Circular 66, Bureau of Plant Industry, U. S. Dept. of Agriculture, 1910. Cotton Improvement on a Community Basis, Yearbook, U. S. Dept. of Agriculture, for 1911, pp. 397–410.

tion of a single type of cotton. Hence the need of a general statement of the underlying principles or physiological factors of heredity that have to be applied in the breeding and selection of cotton.

Facts of nature have an interest of their own, apart from any general inferences or applications. As Emerson has said, "Nature is loved by what is best in us." But when practical applications are to be made the facts must be interpreted. Investigators of heredity propose to apply their results to the breeding of improved plants and animals, and even to human eugenics. In drawing conclusions for such purposes the utmost caution is required, not only in basing our inferences on large numbers of facts but in distinguishing different kinds of facts and understanding their relations to each other. Investigating facts from the wrong point of view is like traveling on the wrong road. Instead of bringing us nearer to the end of our journey, the most diligent effort may only expose us to unexpected dangers. To give advice on breeding problems without taking the underlying physiological factors into account is to invite disaster and confusion. Many attempts have been made to establish a distinction between pure science and applied science, the assumption being that more careful or fundamental researches are made when no practical objects are in view. But in reality the most complete and adequate knowledge is required to meet the test of practical application and thus open the way to further progress.

## THE NATURE OF HEREDITY.

Heredity, the resemblance of offspring to parents and ancestors, is one of the most familiar facts of nature and yet one of the most mysterious. Nobody has been able to imagine any sort of mechanism that would perform the work of heredity, much less a mechanism of the nature of a fluid jelly, like the protoplasm of the living cell. The first theory of heredity assumed that the new organism was preformed in the egg as a minute model that developed to visible size after fertilization. This notion was long since given up, but the idea of models or other determining mechanisms continues to serve as the basis of speculation regarding the nature of heredity. Though it is no longer expected that the microscope will reveal infinitesimal plants or animals swimming in the protoplasm, the hope is still cherished that something in the protoplasm of germ cells may be found to represent the future organism or at least the component parts or "unit characters" of which the bodies of plants and animals are supposed to be built.

Naegeli found reasons for believing that organic characters must be transmitted by solid particles rather than by liquids or solutions, and the idea of material determinants has been greatly elaborated

by Weismann and his followers. But none of the corpuscular theories thus far proposed can be said to convey an adequate conception of the processes of heredity. Characters can be thought of in other ways more consistent with the facts of heredity.

Many of these speculations regarding the internal mechanism of heredity are interesting, but it has yet to be shown that any basis of fact has been secured or that they have been of real assistance in recognizing or interpreting the external phenomena. The science of heredity is still in the first stage of development. Primary questions regarding the normal conditions and manifestations of heredity are still to be answered. Some of the most general and fundamental facts in organic nature, such as the organization of plants and animals into species, and the individual diversity everywhere found among the members of normal species, are left out of account in current theories of heredity and breeding. Though it is hardly possible to understand the nature of heredity without recognizing the conditions of its normal manifestation, this phase of the subject usually receives little or no attention in our educational institutions. Very few students become familiar with the facts of diversity in natural species or even have the need of such familiarity brought to their attention.

Failure to recognize diversity and free interbreeding among the members of species as normal conditions of organic existence has made it possible to look upon uniform, unchanging "pure lines" of descent as examples of normal heredity. But uniform expression of characters is not the form of heredity shown in natural species where free interbreeding forms a connected fabric of interwoven lines of descent. Such interbreeding maintains the vigor and fertility of the group, but these qualities are lost when descent is restricted to narrow strains or individual lines. The vigor secured by the crossing of different lines of descent ought to be recognized and utilized as a normal factor in the physiology of reproduction, instead of being looked upon as something exceptional and monstrous, like the abnormal phenomena of hybridization. Biological evidence indicates that the general application of pure-line theories to plants and animals, or to mankind, would not bring permanent strength or improvement, but would lead ultimately to weakness and extinction.

The individual diversity of mankind, the most familiar fact of heredity, may be taken as an example of the normal condition of expression of characters in freely interbreeding wild species. To accept uniform expression of characters as the normal state of heredity would amount in the human species to the acceptance of identical twins as typical examples of human inheritance. The usual object of breeding superior varieties of domesticated plants and animals is to produce larger numbers of individuals with the

same set of characters, but this is not assisted by assuming that uniform expression of characters is a normal condition of heredity. If uniformity were the normal condition a selected "pure strain" might be expected to remain uniform, but in reality selection must be maintained or the variety will "run out" by returning to the original condition of diversity.

## MATERIALS OF HEREDITY AFFORDED BY THE COTTON PLANT.

The cotton plant affords unusual opportunities for the investigation of problems of heredity. The large size of nearly all the parts greatly facilitates the study of characters and the recognition of variations. The period of flowering is not limited to a few days, but often continues for three months or longer, through the whole period of crop development, so that all of the adult characters can be studied on the same plants at the same time.

The length of the flowering and fruiting season allows the effects of changes of external conditions to become apparent in the different parts of the same plant. Thus, it is possible to learn the extent of the changes that can be brought about, even in the adult plants, by differences of temperature and humidity while the plants remain in the same soil.

The cotton plant has several highly specialized characters that are unusually susceptible of changes in definite ways, whether from genetic or environmental causes. The most specialized features are the two types of branches, different in structure, function, and form of leaves; the double involucre, with two forms of bracts; and the fibrous covering of the seed, with the two types of hairs. The specialized characters are not only more susceptible to the influence of external conditions, but are also most frequently affected by other kinds of variation.[1]

The cotton plant also furnishes an unusual wealth of materials in the way of distinct varietal and specific types. No other genus of crop plants contains so many domesticated species, to say nothing of the endless varietal forms to be found in all cotton-growing countries. While the different types are being compared and tested for cultural and breeding purposes there are ample opportunities for the study of parallel variations and reversions to ancestral characters and of the relation of such variations to differences of external conditions.

[1] Several of the specialized characters of the cotton plant have been described in previous publications of the Bureau of Plant Industry, U. S. Dept. of Agriculture: Bulletin 88, Weevil-Resisting Adaptations of the Cotton Plant, 1906. Bulletin 198, Dimorphic Branches in Tropical Crop Plants: Cotton, Coffee, Cacao, The Central American Rubber Tree, and the Banana, 1911. Bulletin 221, Dimorphic Leaves of Cotton and Allied Plants in Relation to Heredity, 1911. Bulletin 222, Arrangement of Parts in the Cotton Plant, 1911. Bulletin 249, The Branching Habits of Egyptian Cotton, 1912.

In addition to the several distinct species and numerous varieties of cotton in regular commercial cultivation, many unimproved types are scattered through the tropical regions of both hemispheres. Some are in the hands of primitive tropical tribes, while others are still in the wild state. Such materials are needed for the study of heredity, in order to complete the series between normally diverse, unselected species and uniform, line-bred strains, like those that usually figure in laboratory and garden investigations.[1]

Without such comparisons between the behavior of characters in different groups, and the reactions of the same groups to different environments and states of breeding, it is very difficult to learn the expression relations of the different characters or to appreciate the larger relations between heredity and evolution. In the absence of a distinction between uniform pure lines and diverse natural species, any definite change in the expression of a character is likely to be mistaken for an evolutionary development of a new character or a new species, as assumed in the theory of mutation.

The study of cotton, as of many other plants, leaves no doubt that abrupt mutative changes of characters take place and that such changes are often permanent. Some mutations are superior to the parental stocks and are useful as parents of improved strains. Other mutations, and by far the larger number, are inferior and serve to destroy the uniformity of select strains unless recognized and removed. The preservation of uniformity in superior varieties of cotton is only to be accomplished by a vigilant roguing out of inferior mutations.

The same general range of diversity has been found among the members of unselected types of cotton as among the degenerate variations, "sports" or "mutations," that continue to appear in the most uniform strains that have been developed by selection. In the breeding of cotton for weevil resistance and other new requirements it has been necessary to take account of the diversified characteristics of wild species and unimproved stocks that have never been reduced to uniformity by methodical selection.

The fact of mutative change does not prove that the characters of mutations are new or that they represent progressive steps in the evolution of natural species. The wild and unimproved types of cotton are not separated from each other by definite unit-character differences like those that distinguish the mutative variations that appear in otherwise uniform, select strains. That mutations do not

[1] In nature, among open-pollinated (allogamous) plants (and presumably among a great many animals) there is no such thing as a "pure" species which will breed true in all its characters, showing only purely fluctuating variability. It is only by selecting and inbreeding for a few generations that we get "pure lines." The only pure lines in nature are to be found among strictly self-fertilized (autogamous) forms. (See Gates, R. R., "Mutation in Oenothera," American Naturalist, vol. 45, 1911, p. 578.

represent new species is no reason for disregarding their existence, nor for failure to recognize their practical importance.

The methods that have been applied to the study of the cotton plant have been developed through a previous familiarity with similar facts of natural diversity, mutative variation, and definite specialization of vegetative parts in coffee and other crop plants of tropical origin belonging to several different families. Members of many wild species of plants and animals, natives of widely different conditions, tropical and temperate, humid and dry, have been compared and found to represent the same primary condition of individual diversity. Even the wild wheat plant recently discovered by Aaronsohn[1] in Palestine has proved to be a normally diverse interbreeding species, in complete contrast with the uniform self-fertilized strains of domesticated cereals that have figured so largely as the basis of general conclusions regarding the nature of heredity and the principles of breeding.

## HEREDITY IN NATURAL SPECIES.

Interpretations that seem to accord very well with one group of facts appear entirely inadequate when put to the test of more general application. Many theories of heredity and evolution deduced from laboratory experiments are fundamentally at variance with conceptions formed by naturalists familiar with species in nature. Natural species seldom show definite character-unit differences like the mutative variations that have been supposed to represent the origination of new characters and new species under experimental conditions. Laboratory experimenters seldom take into account the constitution of natural species. In like manner field naturalists often disregard facts that have been demonstrated by laboratory experiments, being unable to accept theories that have been deduced from such facts.

The present limited views must give place to a conception broad enough to include the facts of heredity shown in large natural groups as well as those ascertained by formal experiments with select individuals or strains. The apparent conflict only shows the need of studying the subject from other standpoints, with no misleading insistence upon one particular kind of facts to the exclusion of other kinds. Nature is a vast experiment where improved methods of reproduction and inheritance of characters are being worked out in the evolution of millions of different species. Evidence is readily had on almost any point, if we only know where to look for it. The

[1] Aaronsohn, A. Agricultural and Botanical Explorations in Palestine. Bulletin 180, Bureau of Plant Industry, U. S. Dept. of Agriculture, 1910, pp. 42–45. In addition to the facts of diversity reported by Aaronsohn, direct evidence of interbreeding was found during a visit to Palestine in the summer of 1910. (See Report of the Acting Chief of the Bureau of Plant Industry for 1910, p. 24.)

conditions of evolutionary progress in nature must be recognized and accepted as a general basis or background for the interpretation of special groups of facts secured by special methods of breeding.

The idea of heredity as a process of segregation or separate transmission of character units derived from different parents does not comport with the general facts of evolution. Species differ from each other and their members differ among themselves in ways that are not recognized from the laboratory point of view. The development of new characters and organs requires the combination and integration of many variations, as provided by the association of plants and animals into specific groups of freely interbreeding individuals. Mutative variations of select stocks should not be confused with the gradual development of new characters in natural species.

Some writers have considered evolution as a process of isolation and segregation of characters, but cases supposed to represent the origination of new species in this way can be better understood as examples of abnormal variations or reversions. With the facts of heredity limited to a few animals and plants bred in cages and gardens, it is possible to entertain the conception that new species arise by sudden changes of unit characters, but those who are familiar with natural species know that they are very differently constituted. An adequate conception of heredity must recognize the conditions of inheritance among the freely interbreeding lines of descent in natural species as well as the conditions found in selected varieties where the natural network of descent has split into narrow strands or individual lines.[1]

The individual plant or animal represents one of the junctions or knots of the network of descent. Vast numbers of lines of descent pass through each joint of the network, lines that converge from all the ancestors and diverge to all the descendants. The fact that organisms lose their vigor and fertility when removed from the network of descent by being propagated in separate lines, but show renewed vitality when the separated lines are reunited, makes it evident that the weaving of the lines together to form a network of descent has a physiological value. Reproduction in a broad network of descent maintains the vigor and fertility of species, while reproduction in single or narrow lines sustains vitality for only limited periods.

Many kinds of plants and animals can be propagated in simple or narrow lines of descent for a series of generations, but there is nothing to indicate that any method of line breeding will permanently maintain the vitality of a stock. If propagation takes place

[1] Cook, O. F. Methods and Causes of Evolution. Bulletin 136, Bureau of Plant Industry, U. S. Dept. of Agriculture. 1908. See also "The Superiority of Line Breeding over Narrow Breeding," Bulletin 146, Bureau of Plant Industry, U. S. Dept. of Agriculture. 1909.

by self-fertilization or some other form of line breeding, uniform expression of characters may become established in natural species, the same as in pure lines that are artificially bred, though in nature such lines are only temporarily separated from the network of descent of the species. The normal evolutionary species is represented by the network of diverse interbreeding lines, not by the uniform self-fertilized lines. Self-fertilization, parthenogenesis, and vegetative propagation are to be considered as supplementing sexual reproduction, not as adequate substitutes for natural crossing of the lines of descent.

The relation of the network of descent of the species to the maintenance of vigor and fertility has become easier to understand in the light of recent discoveries regarding the nature of the cells that compose the bodies of the higher plants and animals. There is a profound difference in this respect between the higher types of organisms and some of the lower groups. The nuclear elements of the cells that compose the bodies of the higher types are double, so that each cell corresponds to two cells in the lower types. This peculiar condition of double cells arises from a difference in the process of conjugation. In the lower groups conjugation is completed in a comparatively brief period of the life history, while in the higher groups the cells remain in the double, conjugating condition during a very large part of the life history, so that it is possible to build up large bodies composed entirely of double cells, representing a state of prolonged conjugation of the original gametes.[1]

## SPECIES AS PHYSIOLOGICAL ORGANIZATIONS.

In attempting to understand the structure of protoplasm as a mechanism of descent, the structure of the species as a network of descent has been left out of account. Though the association of organisms into species does not serve structural or economic purposes directly, it has the physiological function of maintaining vigor and fertility. From the physiological standpoint it is just as necessary to recognize the existence of the network of descent of the species with normal diversity and free interbreeding, as to understand the cellular and protoplasmic structure of the bodies of individual plants and animals.

That the individual plant or animal represents a social organization of the various kinds of cells that compose the body is a familiar idea among students of structural biology. Moreover, the individual cells are connected into a network by narrow strands of protoplasm that perforate the walls. Even the protoplasm itself is now known to have a reticular or netlike structure.

[1] Cook, O. F., and Swingle, Walter T. Evolution of Cellular Structures. Bulletin 81, Bureau of Plant Industry, U. S. Dept. of Agriculture. 1905.

More complex types of structural units are found in the segments of animals and the internodes of plants. This is most obvious in cases where the numerous metamers or joints that make up the body are also capable of an independent existence. The different kinds of internode metamers that compose the bodies of plants may be compared also with the several different kinds of specialized individuals found in colonies of social insects—bees, ants, and termites. Though many groups of plants and animals have the power of vegetative or asexual reproduction, none of them have been able to dispense with sexual reproduction. For many agricultural purposes vegetative propagation is superior to sexual reproduction, but vigor and fertility are not permanently maintained.

The specific constitution or speciety of living matter, the association of all plants and animals into normally interbreeding specific groups, should be considered as one of the distinctive biological properties or necessary conditions of the continued existence of complex organisms. The perpetuation of all the higher types of plant and animal life seems to be as truly dependent upon the fact that organisms are always associated in species as upon other properties of protoplasm that are usually recognized, such as irritability, assimilation, growth, and reproduction.

In the study of heredity and breeding, primary consideration should be given to the constitution of natural species as networks of interweaving lines of descent rather than to the formal taxonomic idea that species are based on "identity of form and structure," as a dictionary definition states. The identity sought for by the systematist is in reality merely an agreement in a few formal characters that most readily serve the taxonomic purpose of distinguishing the members of one species from those of another.

This formal taxonomic view of species has often misled evolutionists as well as students of heredity. The subdivision of large species into smaller and more uniform groups does not represent the typical condition of evolutionary progress any more than uniform groups represent the typical condition of heredity. Evolutionary progress is represented by changes of characters in large species rather than by the isolation of numerous small species. Heredity, no less than evolution, is a group phenomenon. The specific network of descent rather than the individual line is the fundamental fact of heredity, as of evolution. Not to know the constitution of the species is not to understand the constitution of the germ cell, for the one depends on the other.

The differences found among the members of one large species are often greater than those that serve to separate smaller or more uniform species. The diversity of large species is the most favorable condition for evolutionary progress, as Darwin recognized, and it

also represents the typical condition of heredity and breeding. The diversity found in the human species, for example, is more normal than the uniformity of "pure strains" of domesticated plants and animals. The development of a uniform "pure strain" of a domesticated plant or animal is an agricultural improvement when it enables the yield or the commercial value of the product to be increased, but no one who appreciates the biological nature of such strains would propose to use the same methods for the improvement of the human species.

Many of the variations selected as improvements of plants and animals for economic purposes represent negative changes or suppressions of characters. Instead of the total equipment or content of transmission being increased by constructive additions of new characters or functions, the expression of some of the characters is reduced or omitted altogether. It is a mistake to confuse the results of individual selection with the evolution of species through progressive changes of characters under natural conditions of free interbreeding.[1]

Selection regulates the expression of characters by restricting descent to particular lines that show the desired characters or degrees of expression, but there is no reason to believe that new characters not already present in the ancestry of the group can be brought into existence by selection. The most carefully selected types of Upland cotton do not have larger bolls or longer lint than are found in some of the native Central American stocks of Upland cotton that have not been subjected to conscious selection.

## TRANSMISSION DISTINCT FROM EXPRESSION.

Two distinct processes are involved in heredity. The transmission of characters is independent of expression. If transmission and expression were the same, the transmission of a character would necessarily involve expression. All the characters would be shown in all the individuals that are able to transmit them. In reality a large part of the characters are transmitted without being brought into expression. They may remain for many generations in a dormant or latent condition. The full series of transmitted characters might be compared to the stock carried by a merchant, while those

[1] "The pure line, while a valuable and necessary means of analyzing various problems of heredity, is essentially a laboratory product seldom duplicated in nature among allogamous plants. By continued inbreeding and selection to smaller and smaller differences, races which are more and more uniform may be obtained, as the 'pure-line' work tends to show. But the natural wild species must (unless regularly self-fertilising) be looked upon as an intercrossing population of races whose appearance is ever changing (within limits) from generation to generation, according to the particular series of crosses or 'selfings' which happen to occur in each generation. Some of the races are likely to fluctuate in numbers or be dropped out entirely as conditions change." (See Gates, R. R., "Mutation in Oenothera," American Naturalist, vol. 45, 1911, p. 578.)

that are brought into expression would represent the small assortment placed in the show window.

The failure of a character to come into expression is not the same as a failure of transmission, for the character may reappear in later generations. Though all the lines of descent share the same general equipment or content of transmission, each individual is necessarily limited to the expression of a single set of characters. Transmission may be considered as a permanent, invariable factor or common denominator of heredity; expression as a small and highly variable numerator of the individual fraction.[1]

In this conception of a germ cell as a transmitter of all the ancestral characters modern science affords a curious parallel with the ancient allegory of Pandora, the All-Gifted, the woman who received all the good and evil gifts of the gods for mankind. Pandora was blamed for letting the gifts of the evil deities escape into the world, while those of the good deities were left imprisoned. Bringing the wrong characters into expression may still be considered as the chief impediment of human progress. Pandora was married to Reflection, the brother of Progress. The Greeks were in advance of us in appreciating the importance not only of eugenics but of what might be called "euphanics," or the art of bringing desirable qualities into expression. They recognized the need of training the young by intimate contacts with all the activities of life, instead of limiting education to formal instruction in schools.

The breeder, no less than the educator, has to deal with expression of characters. The processes of transmission are still beyond our control, as well as outside our comprehension. The practical problems of heredity lie in the field of expression. The differences that exist among members of the same species, varieties, or strains, the differences that serve as the basis of selection and of all investigations of heredity and breeding, are differences of expression rather than differences of transmission. Selection is our means of avoiding the expression of undesirable characters, but there is no way to exclude them from transmission, except by destroying the whole stock. For constructive progress it is not enough to reject the obviously inferior individuals. Preference must be given not only to the best individuals, but to those that yield offspring without the undesirable characters. The chief problem of heredity is to understand the laws that control the expression of characters.

In a normally diverse wild type each individual shows a different set of characters, a fact most familiar in the human species. Identical twins illustrate the expression of the same set of characters in two individuals. Uniform, selected varieties or "pure strains" of

[1] Cook, O. F. Transmission Inheritance Distinct from Expression Inheritance. Science, n. s., vol. 25, June 7, 1907, p. 911.

domesticated plants and animals represent the expression of the same set of characters in large numbers of individuals, but the usual normal condition is a varied or alternative expression of different sets of characters. In the Mendelian theory of heredity, transmission is supposed to be limited to a single set of characters. Failure to distinguish clearly between transmission and expression is a frequent cause of confusion and ambiguity in the literature of heredity. Many writers identify heredity with transmission, as in the theory of Mendelism, while others use heredity in the sense of expression.[1]

Apart from this misleading assumption, the special study that has been given to Mendelism in the last decade has been of use in bringing alternative phenomena of heredity into greater prominence. Attention has been given almost exclusively to Mendelian forms of diversity, but other phenomena of alternative expression are of more general significance. The result of alternative expression of characters in natural species is to preserve variations and maintain diversity, even under conditions of free interbreeding. Recognition of this fact removes the ground for the former belief that variations could not be preserved and made effective for evolutionary progress unless they were isolated, because of the alleged "swamping effects of intercrossing." The older idea of the results of mixing different species or varieties was that the characters would finally blend or reduce to an intermediate average, but this no longer appears to be true. The distinctive characters of the parental types are not lost or permanently fused in the hybrids, but continue to be capable of full expression in later generations.

Though an intermediate expression of contrasted parental characters often occurs in the first-generation or conjugate hybrids, this is now recognized as a merely temporary condition. In the second-generation or perjugate hybrids the parental characters reappear in fully contrasted expression instead of being limited to intermediate or blended expression as in the first generation.

The theory of alternative transmission may appear adequate as long as the second generation shows nothing outside the range of the parental characters, but when a wider range of diversity is found, as usually happens in cotton hybrids and frequently in the hybrids of other plants, it becomes evident that crossing has done more than to form different combinations of the contrasted parental characters by alternative transmission. Another effect of crossing

[1] "Our second purpose in this Harvey Lecture is to show that the evidence for continuity in the genesis of certain characters in man and other mammals is very strong indeed; further, that some of these characters, while apparently continuous in origin, certainly become discontinuous in heredity; from which it follows that discontinuity in heredity constitutes no proof of discontinuity in origin." (See Osborn, H. F., "The Continuous Origin of Certain Unit Characters as Observed by a Paleontologist," American Naturalist, vol. 46, 1912, p. 186.)

varieties is to arouse latent characters to expression and thus induce a return toward the normal diversity of the species.

Any definite variation that has once occurred in a species is likely to reappear in undiminished form in at least a part of the offspring or their descendants. New variations do not need to be separated from the parent stock by selection or otherwise in order to escape the alleged "swamping" effect of dilution with the parent form. The principle of alternative expression provides for the development of new characters and functions by accumulation and integration of variations or, in other words, by building up advantageous relations of expression among the different alternative characters. The effect of selection is to regulate the expression of characters and establish the more advantageous combinations.

What there may be in the protoplasm of the cells to correspond to the external features of plants and animals and make possible an accurate transmission of such features from one generation to another is not known. Only the results of heredity are definitely known; the mechanism remains a matter of conjecture. The results afford some indications regarding the workings of the process, but these indications are in the nature of inferences, not direct observations. The characters have to be seen and thought of as external appearances, not as internal entities of the protoplasm. The study of heredity is based simply on observation and comparison of individual plants or animals to see whether they are alike or different; in other words, upon the expression of the characters.[1]

### VARIATIONS AS CHANGES OF EXPRESSION.

Until the nature of the mechanism of heredity is understood no complete answer can be given to questions regarding the causes of variation. Experiments may prove that the expression of a character is modified by an external condition, but do not show how the internal processes of heredity are affected. For some purposes it is sufficient to say that a certain character is caused or induced by a certain condition, but there may be many untraced steps between the external condition or "cause" and the consequent variation.

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[1] "We know already that the experience of the breeder is in no way opposed to the facts of the histologist, but the point at which we shall unite will be found when it is possible to trace in the maturing germ an indication of some character afterwards recognizable in the resulting organism. Till then, in order to pursue directly the course of heredity and variation, it is evident that we must fall back on those tangible manifestations which are to be studied only by field observation and experimental breeding.

"The breeding pen is to us what the test tube is to the chemist—an instrument whereby we examine the nature of our organisms and determine empirically what for brevity I may call their genetic properties. As unorganized substances have their definite properties, so have the several species and varieties which form the materials of our experiments. Every attempt to determine these definite properties contributes immediately to the solution of that problem of problems, the physical constitution of a living organism." (See Bateson, W., "Heredity and Evolution," Popular Science Monthly, vol. 65, 1904, pp. 530–531.)

Many writers have laid emphasis on direct effects of environment as causes of variation. Plants may be kept small or rendered abnormal in other respects by having too little or too much water, heat, or light, or colors may be changed if the tissues are penetrated by chemicals or dyes. To keep a plant small may be considered as a direct effect of environment, but the reduction or suppression of a character is not to be confused with the substitution of a different character. That an external condition, such as temperature or humidity, enters directly into a cotton plant to change the form, texture, or hairy covering of the leaves is not to be assumed. The plant grows in a different way after the conditions are changed and brings different characters into expression.

Indirect, adaptive changes of characters in response to changes of external conditions have more significance in heredity than direct effects, because they represent activities of the plants instead of mere limitations imposed by environment. Still greater interest attaches to the more permanent changes of characters, the definite mutations or reversions that often take place without changes of environment and persist in different environments.

Many changes of expression occur regularly during the development of each plant, in producing the specialized forms of branches, leaves, and floral organs. These changes are also much greater than any induced by differences of external conditions. From the standpoint of heredity the development of each individual plant or animal should be looked upon as a process of changing characters quite as much as the development of the species. Variation in the sense of diversity of expression of characters is as normal for the species as the developmental changes are for the individual.

Many difficulties are introduced into the study of variation by failure to recognize the facts of diversity. With uniformity accepted as the normal condition, it seems logical to begin the study of heredity by seeking for the causes of changes of characters, as so many investigators have done. The nature of the problem is altered when it is perceived that diversity is the normal condition of species and that heredity provides in advance for a wide range of expression of characters. In a practical study of heredity the first object is not to learn causes of variation, which exists everywhere in the greatest abundance, but causes of uniformity, in order to establish and maintain the expression of desirable characters and avoid the expression of undesirable characters.

## NEW-PLACE EFFECTS AND ACCLIMATIZATION.

The power of external conditions to induce profound alterations in the expression of characters could hardly be shown in a more striking manner than by the behavior of the foreign types of cotton

when planted for the first time in the United States. The Kekchi type of Upland cotton, grown under native conditions in eastern Guatemala, is a small, compact, early, productive plant. Raised under Texas conditions it would not have been recognized as the same species of cotton if the origin of the seed had not been definitely known. The experiment was repeated many times with different stocks of imported seed. Many other varieties from Central America and Mexico have showed similar changes of behavior on being brought to the United States.

It is no exaggeration to say that the expression of all of the characters of the Kekchi cotton is changed under the new conditions.

FIG. 1.—Leaf of unacclimatized plant of Kekchi cotton. (Natural size.)

Instead of producing a low, early, dwarf type of plant, as in Guatemala, the Kekchi cotton grows in Texas into a large leafy bush. Many of these huge, overgrown plants remain completely sterile throughout the season, but some of them produce a few small bolls. The changes in the shape and habits of the plants result from the fact that the fruiting branches of the normal plants are more or less completely replaced by vegetative branches.

In addition to these alterations in the habits of growth there are many changes in the form and texture of the leaves, the structure of the involucre, the number of carpels, and the length and abundance of the lint.

The leaves become larger, softer, and more hairy, with more numerous lobes, and have a closed sinus at the base. The extent of these changes may be judged by comparing figures 1 and 2, which represent leaves of the usual form on plants of Kekchi cotton before and after acclimatization. Both plants were grown under the same conditions at Bard, Cal., in the season of 1910. The involucres have more numerous and larger bractlets. The bolls, if any are produced, are much smaller than in Guatemala and have only three or four locks, very seldom five. The lint shortens from nearly an inch and a quarter to an inch or less and becomes very sparse. The fuzzy covering of the seeds may become abnormally developed or may show a greenish color.

FIG. 2.—Leaf of acclimatized plant of Kekchi cotton. (Natural size.)

These changes are not permanent. They represent merely a temporary suppression of the normal characters, not a loss from transmission. In five or six generations the expression of the normal characters is reestablished, and the Kekchi cotton returns to its original condition of fertility. At the same time the bolls increase in size and the fiber shows a length and abundance equal to that of the best plants of the original Guatemalan stock. The 3-locked bolls that occur frequently on the large, infertile, unacclimatized plants are replaced by a normal proportion of 5-locked bolls.

Attention was first called to this difference in the number of locks by Mr. Rowland M. Meade, at San Antonio, Tex., in the season of

1908. Most of the plants grown from imported seed were completely sterile and the others bore only a few bolls. Of 41 plants with bolls, only 5 individuals produced any with 5 locks. In adjacent rows of partially acclimatized Kekchi cotton none of the plants were completely sterile, and the proportions of 5-locked bolls were much higher, as Table I will show.

TABLE I.—*Census of the bolls and locks of unacclimatized and partly acclimatized plants of Kekchi cotton at San Antonio, Tex., Sept. 12, 1908.*

| Seasons. | Number of plants. | 3-locked bolls. | 4-locked bolls. | 5-locked bolls. | Total number of bolls. | Average number of bolls. | Percentage of 5-locked bolls. |
|---|---|---|---|---|---|---|---|
| First | 41 | 39 | 202 | 6 | 247 | 6 | 2.4 |
| Third | 12 | 9 | 215 | 30 | 254 | 21 | 11.8 |
| Fourth | 7 | 5 | 81 | 91 | 177 | 25 | 51.0 |

Similar results were obtained in the season of 1909 at Falfurrias, Tex., where adjacent first and second season plantings of the Kekchi cotton were compared, as shown in Table II.

TABLE II.—*Census of the carpels of bolls and late buds of 25 plants of first and second year rows of Kekchi cotton at Falfurrias, Tex., in 1909.*

| Plant No. | First-year planting (from imported seed). | | | | | | Second-year planting (from seed grown in Texas). | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Bolls. | | | Buds. | | | Bolls. | | | Buds. | | |
| | 3-locked. | 4-locked. | 5-locked. | 3-locked. | 4-locked. | 5-locked. | 3-locked. | 4-locked. | 5-locked. | 3-locked. | 4-locked. | 5-locked. |
| 1 | | | | | | | | | | 22 | 67 | 1 |
| 2 | | | | 2 | 26 | 4 | | 4 | | | 38 | 2 |
| 3 | | | | 1 | | | | | | 3 | 78 | 8 |
| 4 | | | | | | | | | | 11 | 15 | |
| 5 | | 1 | | | 2 | | | | | 2 | 68 | 1 |
| 6 | | | | 3 | 3 | | | | | | | |
| 7 | | | | 2 | 20 | | | | | 10 | 38 | |
| 8 | | 6 | | 1 | 5 | | | | | 4 | 43 | 3 |
| 9 | 2 | 8 | | 9 | 9 | | | | | 4 | 69 | |
| 10 | | | | 3 | 7 | | | 8 | 1 | 3 | 69 | 4 |
| 11 | | | | | | | | | | 2 | 9 | |
| 12 | | 5 | | 4 | 24 | | | | | 2 | 1 | |
| 13 | 2 | 5 | | 20 | 17 | | | 1 | | | 7 | |
| 14 | | | | 4 | 1 | | | | | | 1 | |
| 15 | | | | | | | | | | 2 | 17 | 1 |
| 16 | | 1 | | | 18 | | 1 | 1 | | | | |
| 17 | | | | | 1 | | | | | | 4 | |
| 18 | | | | | 3 | | | | | 1 | 24 | |
| 19 | | | | | | | | | | 5 | 50 | 6 |
| 20 | | | | 7 | 21 | | | | | 9 | 47 | 2 |
| 21 | | | | 11 | 10 | | | | | 8 | 51 | 6 |
| 22 | | 2 | | 4 | 39 | 2 | | | | 4 | 30 | 2 |
| 23 | | | | 3 | 8 | | | | | | | |
| 24 | | | | 3 | 4 | | 1 | | | 3 | 25 | 1 |
| 25 | 2 | 2 | | 2 | | | | 15 | | 5 | 39 | 1 |
| Total | 6 | 30 | 0 | 79 | 218 | 6 | 2 | 29 | 1 | 100 | 790 | 38 |
| Percentage | 17 | 83 | 0 | 25.9 | 71.7 | 2.3 | 6.3 | 90.1 | 3.1 | 10.8 | 85.2 | 4.1 |

A more definite indication of the superior fertility of the second-year planting was afforded by the presence of numerous individuals that produced more numerous and larger bolls than any of the first-

year plants. A count of the bolls of 10 such plants showed a total of 210, of which 2 were 3-locked, 190 4-locked, and 18 5-locked. The 10 fertile plants had less than 1 per cent of 3-locked bolls and 8.5 per cent of 5-locked bolls.

Other examples of variation in the proportion of 5-locked bolls were afforded by a series of plantings of acclimatized and unacclimatized Kekchi cotton in adjacent rows in several localities in California in the season of 1910. Localities with warmer climates produced lower percentages of 5-locked bolls, though the season of planting and the nature of the soil evidently affected the result in ways that other experiments have shown to be possible. Drought or other adverse conditions that reduce the crop also diminish the proportion of 5-locked bolls. In the hot interior valleys of California the proportion of 5-locked bolls in the unacclimatized stock fell nearly as low as in Texas. But in the acclimatized stock the proportion of 5-locked bolls often ran higher than in Texas. (See Table III.)

TABLE III.—*Census of bolls and locks of unacclimatized and acclimatized Kekchi cotton in 10 plantings in California (season of 1910).*

| Localities. | Unacclimatized stock (from imported seed). | | | | | Acclimatized stock (raised for five seasons in Texas). | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Number of plants. | 3-locked bolls. | 4-locked bolls. | 5-locked bolls. | Percentage of 5-locked. | Number of plants. | 3-locked bolls. | 4-locked bolls. | 5-locked bolls. | Percentage of 5-locked. |
| Red Bluff | 19 | 3 | 137 | 34 | 19.5 | 20 | 3 | 322 | 256 | 44.1 |
| Chico | 20 | 6 | 304 | 43 | 12.2 | 23 | 4 | 175 | 275 | 60.6 |
| Stockton | 7 | 0 | 125 | 67 | 34.9 | 14 | 0 | 71 | 200 | 73.8 |
| Visalia | 25 | 16 | 325 | 115 | 25.2 | 3 | 0 | 8 | 7 | 46.6 |
| Stockdale | 17 | 3 | 150 | 105 | 40.7 | 19 | 0 | 96 | [1] 444 | 82.2 |
| Semitropic | 16 | 61 | 451 | 21 | 3.9 | 16 | 2 | 96 | 377 | 79.4 |
| Glendale | 20 | 10 | 284 | 145 | 33.0 | 20 | 2 | 128 | 347 | 72.7 |
| El Centro | 19 | 40 | 77 | 4 | 3.3 | ...... | ...... | ...... | ...... | ...... |
| Meloland | 18 | 13 | 44 | 0 | .0 | 20 | 5 | 219 | 121 | 35.1 |
| Bard | 20 | 181 | 523 | 23 | 3.2 | 10 | 7 | 653 | 730 | 52.5 |

[1] In this instance two 6-locked bolls were included with the 5-locked.

In hot climates, as in southern Texas and in the interior valley of California, adjacent rows planted with acclimatized and unacclimatized seed of the Kekchi cotton show striking contrasts in vegetative development and fertility. The unacclimatized plants grow to several times the size of the others and produce scarcely any cotton, while the acclimatized plants remain small and bear good crops (Pl. I, fig. 1). In the cool climate of Glendale, Cal., near the coast, the rows appeared much more alike (Pl. I, fig. 2), though the acclimatized stock had somewhat larger bolls and better lint, as though a simple selection had been used. The Kekchi cotton also behaves in a nearly normal manner in Kansas and in Maryland.

In acclimatizing a superior type of cotton we do not make the variety over by creating new characters, but merely bring back to

normal expression characters that the variety is already known to possess. Success with this kind of acclimatization depends primarily on knowledge of the normal habits and characters, so that the variety may be guided back to normal behavior by the selection of the individuals and progenies that show most definite and regular expression of the normal characters.

As the variations induced by the new environments seem to extend quite outside the range of ordinary accommodations to external conditions, they have been described under a special name, "new-place effects." The acclimatization of such plants as cotton might be described as a process of avoiding or eliminating new-place effects. Though the new types of cotton have been brought from tropical countries, high temperatures seem to be the chief cause of abnormal behavior in the United States. The summer climate of the Southwestern States is much hotter than that of many tropical countries. Acclimatization might be said in this case to result in greater resistance to heat, for the processes of growth are no longer affected by the high temperatures that induce abnormal development in plants raised from newly imported seed.

## PERSISTENT TRANSMISSION OF LATENT CHARACTERS.

The transmission of latent characters, though familiar to Darwin and many other investigators, is still treated by many writers as a special condition, as in Mendelian hybrids. In reality the latent or variable characters of a species are vastly more numerous than the characters that are expressed with regularity. Instead of being considered rare or exceptional, latency should be recognized as a universal, underlying fact of heredity. Taxonomists prefer to consider only the constant characters, those that are shown by all the members of the species, but the variable characters are significant in heredity and breeding. The same series of variations may run parallel through whole series of related species and genera without becoming established as uniform, taxonomic characters in any of them. Though there seem to be no limits to the transmission of ancestral variations, expression remains limited in each case to the relatively small set of characters that can be shown in a single individual.[1]

[1] Though the formal distinction between transmission and expression seems not to have been drawn, many passages in the writings of Galton present contrasts between latent and patent characters, like the following example:

"From the well-known circumstance that an individual may transmit to his descendants ancestral qualities which he does not himself possess, we are assured that they could not have been altogether destroyed in him, but must have maintained their existence in a latent form. Therefore each individual may properly be conceived as consisting of two parts, one of which is latent and only known to us by its effects on his posterity, while the other is patent and constitutes the person manifest to our senses." (See Galton, Francis, "On Blood-Relationship," Proceedings, Royal Society of London, vol. 20, 1872, p. 394.)

The content or sum total of transmission is increased when new characters are added in the constructive evolutionary progress of a species, but there is no reason to assume that characters once developed ever cease to be transmitted. Evolutionary progress often involves the suppression of some of the more primitive characters, but the substratum of transmission remains; the pandoric equipment of the germ cells is not diminished. The development of each generation follows the path of all the preceding generations. The facts of reversion and recapitulation show that latent and rudimentary characters continue to be transmitted for hundreds and thousands of generations after normal expression has ceased. Socrates described the soul of man as "something sturdy and strong, imperishable by accident or wear," and so it may be said of transmitted characters, that they seem to have a permanent existence, preserved and passed down through unbroken lines of progency.

The persistent transmission of latent characters becomes all the more significant as an indication of the nature of heredity when it is considered that the suppression or reduced expression of characters is a very important factor of evolutionary progress. The addition of any new organ or function is likely to involve reductions or suppressions of other organs and functions, like the progressive reduction of teeth and other bones of the head in the more advanced, large-brained races of mankind. Viewed merely from the standpoint of characters as independent units such reduction may be confused with degeneration, but not when viewed from the standpoint of the species. An abnormal return of a reduced character to full expression is considered as a mark of degeneration, like the heavy jaws that are supposed to characterize certain classes of criminals.

The idea that the characters of adult organisms are represented by discrete particles or "units" in the protoplasm was developed by Darwin in the theory of pangenesis and elaborated by Weismann in his doctrine of the continuity of the germ plasm. In order to explain the inheritance of characters supposed to be acquired from the external environment, Darwin assumed that units or pangens representing the characters migrated into the germ cells from the various parts of the body. Weismann denied the reality of such supposed acquirements of characters from the environment, holding that the germ plasm is not affected by the vicissitudes of the parent organism.

The persistence of latent characters in transmission shows that the germ plasm carries not only the characters that are to be shown by the organism, but also the differences that are to appear among its descendants. In other words, continuity of transmission provides for variation, or discontinuity in expression. In view of the fact that nothing is known regarding the nature of transmission, there is no way to determine whether the characters are really represented

by separate entities in the germ cells. The relations that govern the expression of the characters are of more immediate importance in the study of heredity.

The practical value of selective breeding as a means of regulating the expression of characters is quite independent of the idea that selection affects the transmission of characters. The influence of external conditions upon expression can also be recognized without supposing that new characters have been introduced into transmission. The influence of external conditions is not limited to the usual adaptive changes or accommodations, but sometimes serves to recall remote ancestral characters to expression. The new-place effects exhibited by the cotton plant may be considered as examples of reversions induced by changes of external conditions. The more extreme cases of new-place effects might be described as wholesale reversions to ancestral characters, all of the normal characters being suppressed.

## REAPPEARANCE OF SUPPRESSED CHARACTERS.

The nature of the variations that continue to appear in selected strains can not be understood or the causes of such variations appreciated without taking into account the reserve stock of latent ancestral characters that can be recalled into expression. Selection serves to keep undesirable characters out of expression, but it does not put an end to the transmission of such characters or prevent their return to expression in later generations.

The rule that like parents produce like offspring represents only one phase or condition of heredity, partially attained after normal diversity has been suppressed by selection or line breeding. The production of like from like is the aim of the breeder, though he frequently finds that like produces unlike. The wider rule of nature is that unlike parents produce unlike offspring, not only through resemblance to the two parents, but through atavism, or reversion to more remote ancestors. Normal heredity should be considered as a group phenomenon. The diversities shown by ancestors and relatives are to be taken into account as well as the characters of select individuals or pure lines, if the full range of variation is to be learned.[1]

Without knowing the range of diversity of the natural group the full possibilities of improvement of a domesticated plant can not be

[1] This idea has been stated very clearly by Davenport in the following paragraph:

"To define 'heredity' as the direct and personal relation between the individual parent and the individual offspring is not only to restrict its meaning within too narrow limits but to destroy its significance to the breeder and deceive him as to the actual facts of transmission during descent. 'Heredity' properly refers to the group that constitutes the parentage and the related group that constitutes the offspring." (See Davenport, E., "Principles of Breeding," p. 473.)

judged. Extensions of agriculture into new regions and applications of plant products to new uses are continually calling for improvements along new lines. Characters previously disregarded in selection may become of primary importance and lend a corresponding interest to the varieties or species that are found to meet the new standard of desirability.

Valuable indications for further improvements of types already in use are often to be gained from the variations of related species, and especially from those that have not been reduced to uniformity by selection. Thus a recognition of the existence of weevil-resisting adaptations in stocks of Upland cotton cultivated by primitive Indian tribes in Guatemala and Mexico has opened the way to a study of weevil-resistant characters and cultural factors in the Upland varieties of the United States. After the more definite specializations of the Central American types of Upland cotton were known it was possible to recognize and appreciate the value of parallel series of variations that occur in our United States Upland varieties, though not previously recognized.[1]

That each of the lines of descent of a natural species can transmit the endless peculiarities of its highly diversified ancestry may be difficult to believe until the nature of the process of transmission can be understood, just as it is difficult for the average person to credit the idea of sending many simultaneous messages over the same wire. The only alternative to the acceptance of multiple transmission and variable expression is the assumption that all the mutative variations arising in selected stocks represent the reorigination of the diverse characteristics that the selection of pure lines is supposed to eliminate.

Though many of the facts of biology can be stated in physical terms, the best analogies of heredity are psychical rather than physical. Psychologists have long recognized the probability that the mind retains a permanent record of all the multitudes of impressions received from the senses. The retention of large numbers of impressions in the mind may be compared to the process of transmission, while the return of the different groups of impressions to consciousness is like the expression of characters in individual organisms. Though only a few of the impressions are capable of voluntary recall by the conscious memory, the subconscious record endures and is often revealed in unexpected flashes, analogous to the occasional return of remote ancestral characters to expression. To describe heredity as organic memory is not a mere figure of speech, for the mental faculties are a product of heredity, no less than the physical body.[2]

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[1] Weevil-Resisting Adaptations of the Cotton Plant. Bulletin 88, Bureau of Plant Industry, U. S. Dept. of Agriculture. 1906.

[2] Cook, O. F. Heredity Related to Memory and Instinct. Monist, vol. 18, no. 3, 1908, pp. 363–387.

Heredity may be considered as an organic memory of the previous paths of descent, a memory that is transmitted because it inheres in the protoplasm of the germ cells. There is the same reason for holding that characters have a physical basis or representation in the protoplasm of germ cells as for supposing that impressions have a physical basis in the brain cells. That the mind is able to receive, retain, associate, and reproduce impressions and ideas is a fact even more familiar to us than heredity, yet of memory as a mechanical process we have as little conception as of heredity.

Neither of the logical alternatives so much discussed by the earlier investigators affords an adequate statement of the facts of heredity. There is as little advantage in assuming a definite preformation of each generation in the germ cells of the parents as in holding that reproduction involves an entirely new formation or epigenesis. If taken in sufficiently general senses, both doctrines are true. The forms of the ancestral generations are carried over to their descendants and yet each individual is formed anew after its own unique pattern.

The members of a species appear alike if compared with another species, but when compared more closely with each other they are found to be different. Such diversity is not a mere failure to hit the center of the target of ideal uniformity, but is a positive essential fact that must be taken into account in understanding the nature of heredity. The normal mechanism of heredity that maintains the existence of a species is not adjusted to produce a mere succession of identical individuals.

Though all the members of a species follow the same general course of development, they do not trace exactly the same courses. The fact of evolutionary progress shows that there is no absolute limitation to ancestral characters or combinations. The pathway of hereditary development in a natural species should not be thought of as a simple, narrow line, but as a broad track with many interlacing paths followed by different individuals. The individual differences are to be recognized, as well as the more distinct and widely separate alternatives of expression manifested in sexual specializations and other definite forms of diversity. In species that are divided into sexes or castes, two or more separate courses of development may be recognized. There are many different degrees of such specializations, as of other characters.

Instead of assuming in advance that heredity represents either preformation or epigenesis it is better to begin by recognizing that the course of development is not definitely fixed either before or after conjugation takes place. Many changes and alternatives of expression are possible. Each individual is different, though each is a part of the same network of descent. It is this conception of

hereditary development as the following of a broad, well-beaten track or netlike pathway of development that should be substituted for the older assumptions. The controversies of biologists over preformation and epigenesis are closely analogous to those of anthropologists over monogenesis and polygenesis, the question whether mankind had a single or a multiple origin. Confusion arises in both cases from the failure to perceive the same fact—that evolutionary progress toward new characters is not a matter of single variations or of simple lines of descent, but is a change in a broad network of descent. In applying this distinction in anthropology the term "eurygenesis" was suggested as an alternative of monogenesis and polygenesis. Primitive men, like their present representatives, may be supposed to have constituted a large diverse group rather than a small uniform group or a series of entirely independent groups.[1]

If the mechanical conception of heredity as something in the nature of a system of invisible models, patterns, or determinant particles is to be retained, it must be vastly expanded to include all the different variations or alternatives of expression that are found among the members of normally diverse, freely interbreeding species. Other methods of reproduction, by restricted descent, enable the manifestations of heredity to be narrowed down to conditions of uniformity and definitely contrasted characters which can be interpreted by a simple theory of alternative transmission of character units, but to give exclusive consideration to these specialized states of uniformity is not to solve the underlying problem of normal diverse heredity, but rather to avoid it. It is much easier, of course, to trace the behavior of aberrant characters or lines of descent, those that wander away from the pathway of normal development or are artificially separated from it. This explains why so much more attention has been given to uniform line-bred groups than to diverse groups interbreeding in a normal network of descent.

The problem of heredity is not merely to provide for the formation of the small number of external differences commonly referred to as characters, but for the formation, specialization, and coordination of the almost infinite number and variety of cells that compose the tissues and organs of the bodies of plants and animals. And when it is remembered that each cell must be supposed to bear the determinants for reproducing all the other cells, the mechanical theory becomes a maze of inconceivable complexity. It is true that most of the cells of the higher animals are so specialized that they no longer serve purposes of reproduction, but with plants a large proportion of the cells retain the power of producing all the other kinds of cells. Cases where the leaves as well as the stems are able to produce new individuals by budding have been looked upon as examples of

[1] Cook, O. F. Kinetic Evolution in Man. Science, n. s., vol. 15, June 13, 1902, p. 927.

reproductive specialization, but should be considered rather as representing incomplete vegetative specialization.[1]

The germ cells must be supposed to carry the determinants, not merely of a few general, external features, but of all the internal organs and of the multitudes of cells that are to compose the bodies of their varied posterity. Every external character of a plant like cotton is a collective result of coordinated activities of vast numbers of cell individuals, each highly complex in itself. There is no more need of specialized determinants for the distinctive features of a variety than for the features that are not peculiar to the variety.[2]

It may be that the predication of determinant character units brings biology into more logical accord with corpuscular theories of physics, but this is not so important as to have biological theories accord with biological facts. Only a few of the characters of plants and animals appear to have definite reactions like those that physical chemists explain by their theories regarding the structure of molecules.

To compare organisms with crystals is a very inadequate analogy, but it is at least better than the analogy of amorphous compounds. Because the crystals of a certain substance are always of the same general form it is not held that they are controlled by special particles or determinants. To say that the substance has a property of crystallization does not explain how the crystals are formed, but it at least avoids the need of making a more complex and improbable assumption that there are special particles to control the different angles and planes of crystallization. The same substance may crystallize in a different system when placed under different conditions, but this does not compel us to suppose that new characters have been added. There are regular systems of leaf arrangement in plants even more complicated mathematically than the systems of crystallization in chemicals, but phyllotaxy is subject to variation like other characters of plants.

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[1] In addition to the usually cited illustrations of this condition in Bryophyllum and Begonia, another example was noted by Hance in 1849 in a Chinese plant, *Chirita sinensis*, of the family Gesneraceæ. In this case, as in Begonia, the young plants "sprang indiscriminately from the costa, primary veins, and connecting parenchyma." Hance also refers to reports of the same phenomenon in Ornithogalum and Drosera, members of two other widely separated families. (See Hance, H. F., "On Some Chinese Plants," Hooker's Journal of Botany and Kew Garden Miscellany, vol. 1, p. 141, pl. 5, fig. c.)

[2] That the Mendelian theory of alternative inheritance may not apply to the more fundamental characters has been recognized in the following passage:

"Aside from these cases which show a distinctly non-Mendelian mode of inheritance, it must be remembered that Mendelian analysis can be made only in the presence of differential unit characters possessed by individuals capable of life and of sexual reproduction, and that therefore there can be no test, except under rare circumstances, of the Mendelian nature of the more fundamental vital characters. This leaves it an open question whether the whole of the germ plasm is a complex of such genes as those which give rise to the phenomena of unit characters, or whether, with its wonderful general powers of assimilation, growth, and reproduction, it consists of a great nucleus of which the genes are relatively superficial structural characteristics." (See Shull, G. H., "Germinal Analysis through Hybridization," American Philosophical Society, vol. 49, 1910, p. 290.)

Regularity of expression, whether of frequency or of degree, affords no reasons, either logical or biological, for supposing that the characters of organisms are determined by preformed models or by discrete particles representing different characters. The doctrine of determinants could be applied with more reason to the expression of characters than to transmission. External conditions and internal secretions are already known to act as determinants of expression. That germ cells might be charged in advance with such determinants of expression is quite conceivable, and this supposition would accommodate all the facts that have been used to support the theory of alternative transmission. A convenient division of labor might be arranged on this basis, the undifferentiated protoplasm being considered as the seat of transmission of all the characters, and the chromosomes as determinants of expression, with specialized chromosomes to represent the definitely alternative characters.

## FACTORS THAT CONTROL EXPRESSION RELATIONS.

Whatever the future may bring in the way of discoveries regarding the nature of transmission and expression, it is desirable to avoid further confusion of the two processes. Variations of plants or animals of the same species recently descended from common ancestors represent differences in the expression of the characters rather than differences of transmission.

The processes of expression evidently do not operate independently for each character, but have mutual interrelations, often very complex. The expression of one character may depend upon or conflict with the expression of other characters. In order to secure and maintain the highest degree of expression of desirable characters it is necessary to understand their expression relations. Unless these relations are taken into account the breeder may waste his time in vain attempts to establish the expression of incongruous and unstable combinations of characters. The study of heredity, as far as it is concerned with actual variations of plants and animals, is the study of expression relations. The control of expression relations is the art of breeding.

Potency is the name applied to inherited tendencies of expression. It is not sufficient to define potency as the power of transmitting characters, for the power of simple transmission of characters is a general property of organisms. Potency involves not merely the transmission of a character, but also the inheritance of a condition or factor of expression, something that brings about a strong and regular expression of the character in each generation instead of a weak, irregular, or intermittent expression.

Something more is required for expression than for transmission alone. There must be favorable conditions, internal and external, for each particular character, if full expression is to be gained. Though the mechanism of expression, like the mechanism of transmission, is still unknown, it is evident that external conditions, methods of breeding, and relations with other characters are factors that affect the mechanism of expression, though having no corresponding influence over the mechanism of transmission.

Though some changes of expression relations evidently arise inside the germ cell, others are induced by external conditions. It is safer, for scientific progress, to begin by considering the changes that can be influenced by external conditions or by breeding, and to use these as a basis for understanding the internal relations and the nature of the mechanism of expression. To proceed otherwise, by drawing out series of logical deductions regarding processes that are not open to direct observation, is to disregard the possibility of securing more practical points of view.

Even if it could be shown that certain characters have their residence in certain particles of the protoplasm the problem of controlling the expression of the characters would remain. In all probability it would still be necessary to deal with the characters through the external methods of influencing expression, rather than by manipulating the determinant particles inside the germ cell.

The most effective methods of selection are those that take into account the potencies of the characters. Instead of selection being based merely on the degree of expression attained in the individual parent, it should be based on regularity of expression in the progeny, as is most definitely recognized in the centgener methods applied by Hays to the breeding of wheat. A higher degree of expression may be attained in a few individuals or may result from some unusually favorable external condition, but without establishing a definite potency in the stock. Selection of the lines of descent having the largest and most stable expression of a desired character serves to establish and stabilize such expression, though mutative reversions and degenerate individuals continue to appear.

The effect of selection to increase the yield of a crop is explained by the greater uniformity secured by the rejection of inferior individuals. Yet selection alone can not be relied upon to maintain the largest possible yields. This has been demonstrated in many cases where conjugate hybrids of two strains have been found to produce much larger and better crops than either of the parent varieties grown under the same conditions. Increased vigor secured by crossing has the same practical advantage in improving the crop as planting in a richer soil or using more fertilizer. The superior vigor and

fertility of the hybrids depend largely on their greater powers of resistance to unfavorable conditions.

## CORRELATION AND COHERENCE IN EXPRESSION.

The value of correlation as a guide to selection has been recognized, and attempts have been made to discover useful correlations by elaborate systems of measurements. Regard for the distinction between expression and transmission makes it possible to place the study of correlation on a broader biological basis. Many so-called correlations, such as correlations between size and weight or between length of internodes and total height of plant, represent merely different mathematical statements of the same fact and have very little biological significance.

Biological correlations are to be interpreted in the light of the general fact of coherence of characters in hybrids, the tendency of characters derived from the same ancestral group to remain associated in expression. Characters that remain coherent in hybrids between different species are likely to be correlated in variations of unhybridized stocks. In other words, phylogeny may explain coherence and correlation.

Lack of coherence allows free combinations between the characters of the two parents, according to the laws of chance. This represents the typical form of heredity from the standpoint of the Mendelian theory, but other relations seem to be more common and more important in breeding. The expression relations of the characters in wild or unimproved allies of domesticated species often afford the best clues for the solution of breeding problems that depend upon coherence or correlation.

One of the limitations of the Mendelian theory of heredity is that it is based so largely on the idea of pairs of contrasted characters supposed to be separately transmitted, as in sexual differences. In less specialized kinds of characters, expression has not merely two alternatives, but many possible variations or degrees of expression. Only a few characters have the definitely contrasted polarity of expression of the typical cases of Mendelism. Even among characters that segregate in the later generations in a definite Mendelian manner only a few show either of the parental alternatives of expression in the first or conjugate generation of hybrids. In the great majority of cases the first generation shows different degrees of blended or graded intermediate expressions of the parental characters, or even characters that did not appear in the parents. Thus, when a variety of cotton with naked seeds is crossed with a variety having white fuzz on the seeds the hybrids are likely to have green fuzzy seeds.[1]

[1] Cook, O. F. Reappearance of a Primitive Character in Cotton Hybrids. Circular 18, Bureau of Plant Industry, U. S. Dept. of Agriculture. 1908.

All the facts of Mendelism seem to accord quite as well with the idea of alternative expression as with that of alternative transmission. The more careful investigators of Mendelism are beginning to recognize that only a relative "purity of germ cells," instead of an absolute purity, can be claimed. Occasional variations are found even in characters that have shown the typical Mendelian behavior in large numbers of cases.

Interesting examples of reversion and variable expression of the starch character in sweet corn have been reported recently by East and Hayes. Two explanations are suggested, either that the hypothetical character units, or "genes," are broken up into fractions, some of which remain in the recessive strains, or that the starchy character has reappeared as a result of new variation. The idea of frequent origination of the same character receives more favorable consideration, as the following statement will show:

> Either homozygous recessives (and likewise dominants) are not complete segregates, but products of a partial quantitative separation of genes allowing traces of the dominant character to remain, traces which may sometimes accumulate sufficiently to bring out the dominant character; or, progressive variations are constantly taking place in small numbers, most often along paths that have been passed before.
>
> It is our opinion that dominant starchiness—if it is the same dominant starchiness—has been formed anew. It occurs too rarely to support a partial segregation theory, such as Morgan's. If it is asked why starchiness is the character that arises anew rather than another variation, it is suggested that the peculiar chemical structure of the germ cell of maize may be such that a molecular readjustment is much more likely to bring about starchiness than any other variation. Such a path of least resistance for variations might account for the many cases in animals and plants where the same variation has apparently occurred again and again.[1]

With latency and alternative expression of characters recognized as general conditions of heredity, it becomes unnecessary to resort to theories of alternative transmission, incomplete segregation, or frequent reorigination of characters. If the character units can be broken up into fractions and transmitted in different quantities or regenerated after having been removed completely from the stock, their nature must be very different from what was formerly assumed in the theory of pure germ cells. Such modifications amount to a practical abandonment of the definite features that have hitherto served to recommend the idea of alternative transmission. If each of the starchy variations of sweet corn is to be considered as an origination of a new character, the same reasoning should be applicable to any other character, such as color blindiness, that does not appear in the immediate parents.

[1] East, E. M., and Hayes, H. K. Inheritance in Maize. Bulletin 167, Connecticut Agricultural Experiment Station, 1911. pp. 42–43.

Greater permanence can be ascribed to the underlying mechanism of heredity when the distinction between transmission and expression is recognized, and there is less need of insisting upon discrete units to represent the different characters. Whatever the nature of the mechanism that transmits the characters, it need not be supposed to change because the factors of expression are altered. Many different fabrics can be woven on the same loom by merely changing the patterns. The differences shown in the same stock of plants or animals represent different patterns of expression, all based on the same equipment of transmitted characters.

Even in cases where sex has been found to be determined in advance by the presence or absence of an accessory chromosome in one of the parent germ cells, it is hardly to be held that the sexual characters themselves are directly represented by this chromosome any more than by the heat, sunlight, or other external conditions and internal secretions that have been found to influence the expression of sexual characters in other cases. Increase in the proportion of males in hybrid stocks over the proportions shown in the parent varieties also indicates that the determination of sex depends upon other factors than simple alternative transmission of the sexual characters.[1]

The fact that males are produced from unfertilized eggs of bees and other hymenopterous insects does not warrant the inference drawn by some writers that the female characters are not transmitted by the female sex. Indeed, it is now known that female insects as well as male sometimes develop from unfertilized eggs. Sexual differences, like contrasted Mendelian characters, may be looked upon as examples of alternative expression instead of alternative transmission. Peculiarities of one sex are transmitted by the opposite sex as well as by the same sex and may even be brought to expression, as in an abnormal hen that grows long tail feathers and crows, or in a caponized male that hovers chickens. The specialization of sexual characters has gone on independently in so many different groups of plants and animals that the same relations of expression are not to be expected in all cases. To generalize on sexuality as a Mendelian character is to substitute the same abstract term for a widely varied series of biological facts.

Dimorphic forms of leaves and branches in plants are analogous to the sexes and castes of animals. Each plant may be considered as a colony composed of several different kinds of internode individuals, often capable of an independent existence. The different kinds of internodes show alternative or contrasted expression of characters, like Mendelian or sexual differences. After several of the

[1] King, H. B. The Sex Ratio in Hybrid Rats. Biological Bulletin, vol. 21, July, 1911, p. 104.

lower internodes of a cotton plant have produced vegetative branches there is an abrupt change to a different type of branches, those that bear the flowers and fruit. There can be no question that dimorphic differences represent changes of expression rather than changes of transmission, for the contrasted characters are shown among the internode members of the same plant.

In addition to the functional difference the fruiting branches of the cotton plant have other specializations, like the secondary sexual characters of animals. The leaves of the fruiting branches are usually somewhat different from those of the vegetative branches, and in Egyptian cotton the stipules of the two kinds of branches are quite distinct. The shortening of the internodes of the fruiting branches, as in the so-called "cluster" varieties of cotton, does not extend to the vegetative branches. Varieties of cotton that do not maintain the normal specializations of the different kinds of branches, leaves, and floral parts are undesirable. Abnormal fruiting branches usually produce abnormal leaves and involucres and frequently abort the buds or the bolls.

That the expression of one character often involves the suppression of another is true in the development of a race as well as in the growth of an individual, though it does not appear that the suppressed characters are excluded from transmission. Abrupt changes or contrasts of expression are evidently as natural as gradual changes and as little in need of being explained by theories of alternative transmission.

In the Mendelian system, the suppression of a character to a condition of latency has to be explained by the presence of another inhibiting unit. As Castle has recently shown, it is possible to make very complicated Mendelian problems out of facts that are capable of simple physiological explanations.[1]

### THREE KINDS OF EXPRESSION RELATIONS.

In order to facilitate a more definite study and description of the relations of expression and to avoid the confusion introduced by theories of variable transmission, three principal types of such relations may be recognized. When the expression of one character

[1] "Consider how one unproved hypothesis has been added to another. First, it is assumed that in hornless animals a gene for horns has either been lost or is inhibited. It is equally probable that no gene has been lost and that nothing is inhibited. Secondly, it is assumed that one inhibitor is inferior to one horn-gene in power, but that two inhibitors surpass one horn-gene, yet two inhibitors are themselves overpowered by two horn-genes; without all three of these ungrounded assumptions of the relative valency of imaginary genes the explanation fails altogether. Further, it is assumed that the female is capable of carrying two inhibitors, but the male only one. And, finally, when this colossal structure of hypothesis encounters one well-known physiological fact, the result of castration, that fact is calmly brushed aside. Is this a desirable extension of Mendelian interpretation?" (See Castle, W. E., "Are Horns in Sheep a Sex-Limited Character?" Science, n. s., vol. 35, Apr. 12, 1912, p. 575.)

depends upon or conduces to the expression of another character the relation may be called "symphanic." When the expression of one character inhibits or interferes with the expression of another the relation may be called "antiphanic." When the expression of one character neither favors nor interferes with the expression of another the relation may be called "paraphanic."

These terms can also be defined from the standpoint of correlation, though including a wider range of phenomena than are usually considered in statistical studies. Characters may be called symphanic when they show mutual or positive correlations of expression, antiphanic when they show negative or antagonistic correlations, and paraphanic when there is an absence of correlation.

It may be objected that more words are unnecessary, since the facts can be stated in terms of correlation. As long as the facts are viewed only from a mathematical standpoint the terminology of correlation may be sufficient, though it is often inadequate if not actually misleading, for biological statement of the facts. Negative correlation (antiphany) and absence of correlation (paraphany) are no less positive facts from the biological standpoint than the cases that are described as positive correlation (symphany). It may be that the meaning of the term "correlation" will become modified in practice so as to have more of a biological and less of a mathematical significance. The object to be gained in the meantime is the recognition of the practical importance of the study of expression relations from the biological standpoint, instead of depending upon the mathematical method of the empirical discovery of such relations.

Some writers have concluded that correlations are too rare to be of use in practical breeding, because of the many cases of apparent absence of correlation that result when measurements are applied at random, in attempting to make empirical discoveries of correlations. While it is probably true that the paraphanic characters outnumber the symphanic and antiphanic characters, it has also to be considered that many of the so-called characters employed in the search for correlations represent merely formal statements, framed without regard to the real relations of expression.

With characters framed from the biological standpoint it is to be expected that the laws of correlation, of variation, and of coherence of characters in hybrids will be found to have very general application, as long since recognized by one of the greatest of botanical naturalists.

> In all stable groups, whether of higher or lower rank, there should be some correlation of structure in every organ, which it is the systematist's part to trace out and rate at its true value.[1]

[1] Spruce, R. Equatorial-American Palms. Journal, Linnean Society, Botany, vol. 11, 1871, p. 91.

## MEASUREMENT OF EXPRESSION RELATIONS.

It is often interesting, and may sometimes be important, to make accurate determinations of the extent of correlation in the expression of two characters in a particular group of plants or animals. Elaborate systems for measuring and expressing different degrees of correlation have been recommended by mathematical biologists. If these relations of expression represented natural constants like the atomic weights of elementary substances or the angles of crystals, the labor of very accurate determination of all such relations might be justified. But there is no reason to believe that relations of expression are less varied than other biological phenomena. They are often changed in the same group or even in the same individual under different conditions of existence. Correlations will appear constant, of course, as long as the expression of the characters is not changed, but any influence able to disturb expression is likely to interfere with correlation as well.

It is manifestly desirable that biological study of expression relations precede mathematical study to avoid the waste of labor in ultra-accurate determinations of relations that have little or no biological significance. An almost infinite number of mathematical relations can be formulated among the parts of any of the higher plants or animals. If the measurements of all conceivable relations were considered necessary as a basis of biological study the future of biological science might well be considered hopeless. It is a mistake to consider the making of statistical measurements as an independent method of biological investigation. The importance of biological statistics resides almost entirely in their value as a more direct and accurate method of stating relations revealed or suggested by familiarity with facts gained through other methods of investigation.

When mathematical analysis precedes biological analysis the facts are likely to be brought into entirely artificial and misleading relations. A fact that appears altogether trivial from the statistical standpoint may be extremely significant from the biological standpoint, such as the appearance of a few individual mutations among thousands of unvaried examples of a pure stock. The most striking example of correlation, where groups of characters derived from the same parent show coherence in expression, are capable of direct observation, without the need of mathematical demonstration. Mathematical statements of such compound relations are difficult to frame, and the facts are not rendered any more intelligible or more practically useful after such treatment. In critical cases it might be important to learn which of a series of coherent characters were more closely associated, but this would require only a comparison of simple correlations. There would still be no practical need of reducing a compound correlation to a mathematical expression.

The idea that all biological facts are enhanced in value or interest by being stated in mathematical form is to be understood as one of the results of the undue emphasis generally placed on mathematical studies in educational institutions. It is easier to occupy the student with mathematical formulæ than to develop his interest in the multitudinous details of plant or animal life, and allow him to secure the familiarity with nature that is necessary as a basis of biological judgment. The tendency of educational institutions is to formal instruction in biology, as in other subjects. The mathematical substitutes for biology afford more satisfactory materials for pedagogic purposes, and especially for dealing with large bodies of students.

Coefficients of correlation between different characters, such as stature and susceptibility to disease, are useful, of course, for insurance companies interested in the longevity of mixed populations, but nobody has explained how such coefficients are to be used by the breeder of select strains. Selection, with the breeder, is not a matter of taking average risks on a large number of individuals, but of finding and propagating the best individuals. Such selection must be based on biological types, not on mathematical types or statistical averages.[1]

To say that a variety or type of cotton has a tendency to variation in a certain direction may seem too loose and indefinite for scientific purposes. Writers who aim at mathematical precision often object to such statements. But when the facts themselves are indefinitely variable it is not unscientific to describe them in appropriate language. To say that a stock has a tendency to vary merely means that some individuals are likely to show the variation in question, while others do not, which is true of many characters. While it is interesting in all such cases to make more accurate determinations of the extent of variations in different stocks or in different conditions, it is first necessary to recognize that the tendency exists. To record such as observation is quite as proper and as truly scientific as for an explorer to record the general position of a range of mountains, though he may not be able to climb the peaks or even to establish their exact locations.

[1] Bateson has called attention to the fact that mathematical treatments may conceal biological differences which are apparent from direct observation: "As a matter of fact, even in the case of Nigella, differentiation was detected not by the seriations, but by common observation. When the differentiation has been once detected, its influence can be seen in the seriations. This is a mere accident. If the material had happened to contain a certain proportion of a second race with a 'mode' on 10 or 13 and a secondary 'mode' on 8—a condition familiar in plants (from F. Ludwig's beautiful researches)—the differentiation might have been completely masked in the seriations. As it is, the seriations alone contain nothing which prove the existence of differentiation. We happen to know otherwise that high numbers are associated with centrals and lower numbers with laterals. This is not revealed by the seriations. For all they show, the irregular distribution might be due to ordinary discontinuous variation, obeying the laws which F. Ludwig has shown such distributions commonly obey." (See Bateson, W., "Heredity Differentiation and Other Conceptions of Biology." Proceedings, Royal Society of London, vol. 69, p. 205.)

It is not surprising that investigators who approach biology from the standpoint of the physical sciences, without becoming familiar with the protean diversity of species in nature, should overlook the essential flexibility of the processes of reproduction. Elaborate measurements often convey misleading impressions of regularity or secure too exclusive attention to phenomena that lend themselves to mathematical forms of expression. The following statement in a recent review of biometrical literature affords further evidence that this danger is beginning to be appreciated:

One who follows the current literature of agricultural science, in a broad sense of the term, can not fail to be struck with the rapidly increasing use of these mathematico-statistical methods during the last few years. In so far as the methods are correctly and appropriately used this is a most commendable movement. But it must always be kept in mind not to let admiration for the method per se blind one as to the real significance and importance of the biological problem attacked. The futility of dealing biometrically with data or problems which lack a sound biological basis is obvious. The indiscriminate application of biometric methods to all kinds of data is easily seen upon critical examination to have only so much value or validity as resides in the original data themselves. It is particularly important that this point be kept in mind in agricultural work along biometric lines, because of the great ease with which mere statistics can be collected in this field and the consequent temptation to collect them without critical consideration of their meaning and worth.[1]

### UNIFORM EXPRESSION OF CHARACTERS.

Uniform expression of characters is secured in domesticated varieties by vegetative propagation or by selective line breeding. It is not a typical condition of heredity in normal species nor an ideal in eugenics. Agricultural breeding is largely a problem of replacing diverse stocks with more uniform breeds or strains. The object of general investigations of breeding is to learn the best methods of producing uniform strains of domestic plants and animals and of preserving uniformity through many generations.[2]

The tendency to look upon uniform expression of characters as the normal condition of heredity is reflected in the terms that have been proposed for the designation of uniform groups of plants or animals, such as "pure race," "pure line," "elementary species," "biotype," and "genotype." Though proposed in connection with different theories, these words all have reference to the idea of heredity as naturally fixed and definite, as shown in uniform groups or series of individuals. The existence of normal species of diverse interbreeding individuals is disregarded.[3]

[1] Pearl, Raymond. Some Recent Studies on Variation and Correlation in Agricultural Plants. American Naturalist, vol. 45, no. 535, 1911, p. 415.

[2] Cook, O. F. The Superiority of Line Breeding over Narrow Breeding. Bulletin 146, Bureau of Plant Industry, U. S. Dept. of Agriculture. 1909.

[3] The word "genotype," which several writers on heredity have adopted recently from Johannsen, is objectionable from the standpoint of systematic biology because it was already in use to designate the specimen or species that serves as the type of a

In cotton, and doubtless in other open-fertilized crops, a breeder sufficiently familiar with the peculiarities of his type can maintain a higher degree of uniformity by roguing out the aberrant plants than by the use of progeny methods, with roguing neglected. The uniformity of the Triumph cotton, as maintained by the originator of the variety, Mr. Alexander Mebane, at Lockhart, Tex., was found, some years ago, to be greater than that of any of the varieties that had been developed by the use of the progeny rows. Strictly speaking, the pure-line or pedigree method of breeding is not applicable to cotton in actual practice. The methods of selection that have been worked out for wheat and other self-fertilized types can not be expected to produce the same results with open-fertilized plants like cotton. If the parent plants are not selected with care as representatives of a single varietal type, the crossing that takes place in the progeny rows is the same as when different varieties are planted together for comparison and testing. Nobody would seriously propose to save the seed of such plantings with the idea of securing pure stocks. Without strict adherence to the varietal type, the progeny-row method is not only unable to produce uniform varieties of cotton, but is more likely to maintain diversity of continued crossing. If a plant has been selected because of any divergence from the varietal type, the seed ought not to be grown in the same block with the progenies of plants that represent adherence to the type. In other words, variations and progenies should be recognized as different kinds of material and kept apart. The breeding of new varieties by the selection of superior variations is a task quite different from that of preserving the uniformity of superior strains by selecting for close adherence to type. Varieties are originated by preserving variations, but are preserved by rejecting variations.

A thoroughly uniform variety represents a complete suppression of the normal diversity or heterism usually to be found among the members of natural species. Though differences due to external conditions should not be allowed to interfere with the recognition of uniform groups, there is a practical necessity of placing the members of a group as nearly as possible under the same conditions if uniformity of expression is to be judged. The basis of selection to maintain uniformity is not a mere ideal type or artificial standard estab-

genus, as proposed by Schuchert in 1897. (Science, n. s., vol. 5, p. 639; see also Bather, F. A., Science, n. s., vol. 32, Dec. 30, 1910, p. 953.) The following new definitions have been offered recently by Dr. G. H. Shull: "Genotype, the fundamental hereditary constitution or combination of genes of an organism." "Biotype, a group of individuals possessing the same genotype." "Pure line, a group of individuals traceable through solely self-fertilized lines to a single homozygous ancestor." In an earlier paragraph is the following explanatory statement regarding pure lines: "There is another prevalent misconception regarding 'pure lines' to which attention needs to be called. The word 'pure' in this connection does not refer to the genotypic equality of the individuals, but only to the exclusion of all crossing as a source of genotypic differentiation." (See Science, n. s., vol. 35, Jan. 5, 1912, p. 28.)

lished by score-card reckonings of the values of different characters, but is an actual, visible type, represented by the normal members of the variety as they exist in the same field. Familiarity with the variety is therefore to be considered as the first qualification for undertaking the work of selection or roguing to maintain the uniformity of a select strain.[1]

As the expression of the characters varies with conditions, each field of cotton may need to be judged by a standard of its own. Even in parts of the same field, plants that belong to the same uniform stock may show considerable differences that prevent the application of any absolute standard, except the standard of uniformity itself. Every plant is to be rejected that shows any sign of being different from its neighbors. Superior variations need to be removed, no less than inferior variations.

This method of preserving uniform varieties by rejecting all deviations from the type has often been confused with mass selection but is essentially different. Mass selection simply preserves individuals or lines of descent that show one or more desired characters in a special degree, without requiring that such superior individuals shall conform in other respects to a definite varietal type. The object of conservative or agronomic selection is not to originate or to improve varieties but to maintain the uniformity of superior strains already separated. It is worth while to compare this form of selection with others and to consider their relations to uniformity of expression. The different forms of selection may be described briefly as follows:

Natural selection represents an irregular and usually a partial application of many standards. Adverse conditions are not applied equally or at the same time to all the members of a natural species. The result of natural selection is to discriminate against individuals and lines of descent that are inferior with respect to the various requirements of existence under natural conditions, but such selection would not be expected to develop a state of uniform expression of characters.

Mass selection involves a more consistent application of one or more standards of superiority, but without reference to uniformity in other respects. The result of mass selection is to secure a higher average of expression of desired characters, but without establishing any general uniformity by the separation of the families or lines of descent that have the most regular expression of characters.

Individual selection goes beyond mass selection by choosing superior individual plants to serve as parents of select strains. It avoids crossing among the descendants of different types of superior indi-

[1] Cook, O. F. Cotton Selection on the Farm by the Characters of the Stalks, Leaves, and Bolls. Circular 66, Bureau of Plant Industry, U. S. Dept. of Agriculture. 1910.

viduals, which is one factor of diversity in groups maintained on the basis of mass selection.

Progeny or centgener selection is a more careful form of individual selection based on comparison between progenies of superior individuals to determine the regularity of expression of characters, the so-called transmitting power of the parents of the different progenies.

Agronomic selection is the rejection of all offspring or descendants that deviate from the standards of the superior parent or progeny group.

As a means of preserving the uniformity of select strains agronomic selection supplements progeny selection and is more effective. Instead of relying entirely upon the progeny or pedigree, the uniformity of the stock is guarded in each generation by inspection of all individuals that are to be used for purposes of propagation, in order to reject any individuals that are inferior or that have varied from the type.

With many domestic animals, and with some plants, it is practicable to renew individual or progeny selection with each generation. But with cotton and similar open-fertilized annual field crops it is much more difficult if not quite impracticable to apply these methods on a sufficient scale to secure select seed in commercial quantities. Hence the necessity in such cases of recognizing agronomic selection or roguing to type as a regular responsibility of every seed grower or farmer who desires to maintain a uniform variety of cotton. And hence, also, the desirability of distinguishing this method of selection, based on the recognition of a definite type, from ordinary mass selection by score cards or other partial standards, without primary reference to uniformity of expression.

The necessity of agronomic selection as a means of preserving the uniformity of superior varieties is not appreciated from the standpoint of theories that look upon uniformity of expression as a natural condition disturbed only by hybridization or mutation. Apart from such accidents, it is assumed that a pure line, once separated, will remain uniform indefinitely. This theoretical assumption is often allowed to obscure the practical necessity of continued selection.

Johannsen's theory of genotypes and biotypes contemplates a condition of absolute fixity of expression, even to the extent that there shall be no heritable differences among the later descendants of the stock. Fluctuations due to differences of environment are admitted, but nothing is supposed to be gained or lost by further selection. If any definite variation can be detected the stock is pronounced impure or a mutation is supposed to have occurred. In view of the fact that no such absolute and permanent uniformity of expression

of characters is secured, even by vegetative propagation, it may be doubted whether this idea of genotypes and biotypes represents anything that has an objective existence. Judged by the standards of the genotype hypothesis all stocks must be considered impure or else subject to very frequent mutation.[1]

By selection of the lines of descent that show the most regular expression of a desired set of characters, relatively uniform groups are obtained, but these are not biotypes or genotypes in the sense of primary or antecedent states of heredity. They are merely incidental or artificial exceptions to the general law of diversity. Their uniformity is no indication of pure ancestry, but merely a result of the restriction of descent to narrow lines or to a single parent, in species capable of self-fertilization or vegetative propagation. Uniform groups secured by special methods of reproduction are not more natural or more typical of the general conditions of heredity in plants and animals than identical twins would be as examples of heredity in the human species. Twins are not more pure of ancestry than normally diverse children born of the same parents, nor do they afford any reason for believing that a race of uniform ancestors ever existed.

There can be no objection, of course, to the study of identical twins or of other uniform groups of animals and plants by any refinement of mathematical methods of investigation, but mathematical elaboration should not be allowed to mislead us regarding the biological nature of such groups. Their suitability for mathematical treatment does not make them types of normal heredity. Instead of being biotypes or genotypes, select strains do not represent the natural state of heredity in which life and generative power are maintained, but an artificial condition of uniformity that leads finally to weakness and extinction.

The theory of genotypes has met with prompt acceptance from mathematical writers on heredity, but this should not be allowed to obscure the biological facts that make agronomic selection necessary. It is natural that mathematicians should prefer to deal with something that appears definite and fixed, something adapted to their methods of elaboration. But there is nothing as yet to indicate that the field of normal heredity presents any such constants as mathematicians desire to discover. The unknown quantities are too numerous and too intricately related to be resolved by any refinement of mathematical analysis. Biological analysis is a necessary preliminary, not only to distinguish the different factors, but to learn something of their relative importance and interrelations.

[1] The statistical evidence offered by Prof. Johannsen as the basis of the genotype theory was reviewed by Yule and pronounced inadequate. (See Yule, G. U., "Professor Johannsen's Experiments in Heredity," New Phytologist, vol. 2, 1903, p. 235.)

As affording more adequate means of describing the results of biological analysis, mathematical precision of quantitative determinations is very important. But mathematical elaboration considered as a method of investigation is as futile as the logical or metaphysical elaboration formerly so popular and now so little regarded. Zeal for measurement is not the same as biological interest and familiarity with the characters or behavior of the plants. Mathematical biologists have, of course, no conscious intention of placing figures before facts, but the method is often allowed to influence the choice of materials used as the basis of inference. Uniform groups represent a mathematical ideal, and this leads to their acceptance as the normal condition of heredity, even in cases where they are known to be an artificial product of the breeder's art.[1]

## PHYSIOLOGICAL STANDARDS OF EXPRESSION.

The extent to which a stock will appear uniform from a statistical standpoint must depend largely upon the characters that are chosen and the perfection of the system of measurements. Varieties that have been brought to a high degree of uniformity in some characters may continue to show a wide range of differences in other respects. It is known, for example, that the types of Indian corn selected for uniformity of ear characters often show notable diversity in vegetative characters. The same is true of the sugar beets that have been so persistently selected for high sugar content but with little or no regard to the establishment of uniform types of plants.

And even though the members of a stock express the same set of characters in the morphological sense, different degrees of physiological strength or weakness may be manifested in the more or less vigorous growth of the vegetative parts or in the size or number of seeds. Such differences in vigor or productive efficiency are as likely to be inherited as morphological peculiarities, especially in line-bred stocks. There is no reason to expect that any two lines of descent would represent absolutely the same level of physiological efficiency, though it is to be expected that many lines of a carefully selected stock would agree within the limits of experimental error in testing. In view of the fact that differences between experimental rows of the same stock grown under the same conditions are seldom brought within 5 per cent and often run to 15 or 20 per cent, it is easy to understand that considerable differences may often remain hidden within the range of experimental error. Failure to detect such differences experimentally affords small reason for declaring that they do not exist. Some writers have considered vigor and fertility as

[1] Cook, O. F. Pure Lines as Artifacts of Breeding. American Naturalist, vol. 43, 1909, p. 241.

"unit characters," but even on that assumption the possibility of slight differences would need to be admitted.

The mistake of relying upon pedigrees or upon morphological uniformity of expression of characters as standards of practical breeding is now widely recognized. Selection of superior individuals as parents of pure strains is now based on the physiological standard of actual performance of the progeny, instead of upon ancestry alone. Yet even this refinement affords no complete assurance of maximum yield, for it has been found that the precautions applied to insure the purity of the stock have the effect of reducing the physiological efficiency of reproduction. Instead of remaining equal to the superior ancestor or to each other, pure lines of descent show different degrees of vigor and fertility. Even plants that are propagated from cuttings do not remain forever the same. Breeders familiar with plants like strawberries and potatoes recognize the fact that varieties eventually run out; that is, decline in fertility, vigor, or resistance to disease. A recent writer reports a reduction of the size of the meshes of the network of veins in the leaves in old grapevines and considers this as a phenomenon of senility.[1]

Persistent selection excludes degenerate individuals and lines of descent. The stock is kept nearer to the standard of its best members, but the utmost refinement of pure-line breeding may still fall short of the full possibilities of production. In the very nature of the case a select strain separated from the normal network of descent of the species and artificially excluded from crossing is placed at a disadvantage in relation to vigor and fertility. The physiological value of crossing between different lines, as occurs in the network of descent of natural species, must be taken into account if the vigor and fertility of domesticated plants and animals is to be maintained. This physiological factor of heredity has recently received recognition in connection with the corn crop, as the following statements will show:

Increased yields are obtained by making the yield of the individual plants more uniform, even when the full possibilities of production are not approached. The best plants of a highly bred variety are not conspicuously more prolific than the best individuals in fields from unselected seed * * *.

Though necessarily impeded by inbreeding, important advances in yield have been made by means of close selection, but the value of these improvements

[1] "Since the leaves borne by cuttings showed but slight increase in the proportion of carbohydrate-producing tissue as compared with those on the original plant, it would appear that vegetative propagation can not and does not produce a young plant. The fact that the normal span of life for woody trees and vines extends in some cases over hundreds of years accounts for the fact that the approach of senility in vegetatively propagated plants is not more obvious. Plants which naturally reproduce by seed will tend to 'run out' after long-continued vegetative propagation, ultimately dying of senility, and it is therefore incumbent upon our plant breeders to develop new varieties from seed to take their place." (See Benedict, H. M., "Senility in Meristematic Tissue." Science, n. s., vol. 35, Mar. 15, 1912, p. 422.)

should not be allowed to obscure the fact that the full possibilities of production are not reached until the increment of vigor obtained by crossing has been added.[1]

Continued selection * * * yielded very promising results with corn during the early years of its application, but the later generations failed to fulfill this promise. Definite reasons for this comparative failure in the corn-breeding work of the United States can now be given, for within the last few years investigators have arrived at some understanding of the underlying principles concerned. These principles are yet but imperfectly understood, but they are sufficiently clear to show that practical corn breeding must undergo a radical change in method if it is to take advantage of the full possibilities which lie open to it * * *. All methods now in use for the improvement of corn are by the application of the selection principle and tend sooner or later toward inbreeding. As corn naturally produces the best results when crossed, we hold that all methods now used are wrong unless combined with some method for continuous crossing.[2]

The neglect of this factor of vigor obtained by crossing is only one of many examples of a general tendency of scientific men to disregard the practical value of any principle or factor that they are unable to explain. Why it is that crossing gives increased vigor is still quite unknown, but the fact has been recognized since the earliest times and has been repeatedly verified by scientific experimenters. Half a century ago Darwin performed many experiments and reviewed a large volume of evidence on the effects of crossing and reached general conclusions which no subsequent writers have overthrown, though such facts have often been disregarded in the discussion of abstract theories. The following statements show the results of Darwin's study:

On the other hand, long-continued close interbreeding between the nearest relations diminishes the constitutional vigor, size, and fertility of the offspring, and occasionally leads to malformations, but not necessarily to general deterioration of form or structure * * *.

These two great classes of facts, namely, the good derived from crossing, and the evil from close interbreeding, with the consideration of the innumerable adaptations throughout nature for compelling, or favoring, or at least permitting the occasional union of distinct individuals, taken together, lead to the conclusion that it is a law of nature that organic beings shall not fertilize themselves for perpetuity.[3]

These opinions were formed in spite of the fact that Darwin was familiar with a few plants that seemed to be specially adapted for self-fertilization. But with his wide knowledge of the organic world, he was inclined to look upon such cases as exceptions and preferred to establish his conclusions on the more general condition.

[1] Collins, G. N. The Importance of Broad Breeding in Corn. Bulletin No. 141, pt. 4, Bureau of Plant Industry, U. S. Dept. of Agriculture, 1909, p. 42.

[2] Hayes, H. K., and East, E. M. Improvement in Corn. Bulletin 168, Connecticut Agricultural Experiment Station, 1911, pp. 3 and 9.

[3] Darwin, Charles. "The Variation of Animals and Plants Under Domestication," vol. 2, p. 159.

Since Darwin's time the biological evidence for the universality of crossing in natural species has continued to increase. The wild types or less "improved" varieties of cereals and other domesticated species have been found to be cross-fertilized. It has also been perceived that even highly specialized adaptations to aid in self-fertilization afford no reason for concluding that the same species does not profit by occasional crossing.

Some species are better adapted than others for maintaining their existence by vegetative propagation or self-fertilization, but it does not appear that any of the higher types of life, either plant or animal, are able to exist permanently without crossing.

The cotton plant is one of many that are adapted for crossing as well as for self-fertilization. In the Egyptian type the stigmas are exserted beyond the stamens and fertilization is more dependent on crossing than in Upland varieties. Here the stigmas are partly immersed among the stamens, so that the opening of the anthers brings the pollen into direct contact with the stigmatic surfaces. That varieties will be found to differ in their ability to tolerate long periods of self-pollination or strict selection is to be expected. Experiments with the artificial self-pollination of Upland and Egyptian cotton do not seem to have furnished any evidence of injury to the later generations of the plants. There is a frequent failure to set seed from artificial self-pollination, but this is also true of artificial cross-pollination. Adverse effects from self-fertilization have been reported recently in Indian cottons.[1]

How the effect of crossing is produced is still as much of a mystery as the other processes of heredity, but the lack of an explanation need not prevent a recognition of the fact, nor of its great physiological importance. The old idea was that inbreeding resulted in some positive injury or poison to the offspring, but from the present point of view we can consider the evil effects as due to an absence of some positive quality necessary for the activity of the protoplasm, some stimulating tension or antagonism that may be aroused by the presence of two kinds of protoplasm derived from different lines of descent. Lack of the stimulation or bracing effect of crossing allows the mechanism of heredity to run down; vigor and fertility decline, and degenerative variations appear.

### EXPRESSION REGULATED BY SELECTION.

The benefits of selection must appear greatest in a stock that is declining in productive efficiency. The larger the proportion of small or weak individuals or progenies the greater the contrast with

[1] Leake, H. M., and Prasad, R. Notes on the Incidence and Effect of Sterility and of Cross-Fertilization on the Indian Cottons. Memoirs of the Department of Agriculture in India, Botanical Series, vol. 4, January, 1912, p. 37.

the superior lines that are separated by selection. The rejection of the weaker or more inefficient lines brings the average of the stock back toward the standard of its best members, but it is a practical error to expect that such a standardization of expression will be maintained without further selection. The functions of selection in regulating or stabilizing expression and in preserving the uniformity and productive efficiency of superior stocks is quite as important as that of separating the superior lines to form new varieties.

The separation of a select strain of a plant like cotton is an important agricultural improvement, for it enables a larger crop and a better quality of fiber to be produced. But this does not mean that the strain itself is being improved or placed in a better physiological condition by being kept from crossing with other varieties. There is no reason to suppose that a variety or strain of cotton would last indefinitely, even if it were selected with the utmost skill and persistence. But for practical reasons it is important to know how to preserve select strains in uniform condition as long as possible, so that they can be utilized to the fullest extent for purposes of production. The farmer has the same reason for removing the degenerate plants from his seed field as he has for pulling out the weeds, and a further reason in the fact that the progenies of the good plants will be rendered inferior by crossing if the bad plants are allowed to remain.

A well-bred type of cotton might appear to support the idea that permanent uniformity of expression had been established, if observation were confined to a limited number of plants grown under favorable conditions. But if sufficiently large numbers are examined, or numerous experimental plantings are made in different localities, many definite variations or mutations are likely to be found. From a statistical standpoint such variations may appear insignificant, but they throw light on the degeneration of varieties. In one examination of the Triumph variety of Upland cotton growing under its native conditions at Lockhart, Tex., only three definite variations were detected in about 50 acres. On the other hand, about 2 acres of cotton raised from seed of the Lockhart stock at Kerrville, Tex., showed frequent mutative variations.[1]

If the uniformity of the Triumph cotton at Lockhart had not been ascertained it would have been easy to make the usual assumption that the stock had not been carefully selected, but this theory was definitely excluded by the uniform behavior of the Triumph stock, not only at Lockhart, but in many other places in Texas and other States where very uniform fields of cotton have been grown from Lockhart seed.

[1] Cook, O. F. Local Adjustment of Cotton Varieties. Bulletin 159, Bureau of Plant Industry, U. S. Dept. of Agriculture. 1909.

Some farmers believe that the Triumph stock is especially liable to a breaking up when carried to new localities, though it does not appear that any adequate comparisons have been made with other varieties to determine this point. That such numerous and definite variations should appear in one of the most uniform and carefully selected varieties of cotton is interesting from the standpoint of heredity. It also suggests an important question in breeding, whether there are not natural limitations in uniformity, as well as limitations in vigor and fertility, in varieties that are carefully selected for the expression of a single set of characters.

Renewed assurances of the value of Mendelism for the establishment of pure lines has been given by Bateson in a recent address. The existence of any general tendency to degeneration in pure-bred strains is denied, the possibility of degeneration by failure of expression of certain characters as in albinos and short-jointed forms like the cluster cottons being left out of account. The assumption that all variations must be due to crossing or to incomplete analysis into pure lines is reasserted. The theory is evidently to be retained, even though experimental facts have to be discredited. That degenerate variations show alternative inheritance like Mendelian hybrids is taken to mean that crossing must have occurred. But if it can be positively shown that the variations are not due to crossing, the rogue throwers must constitute a distinct class which can be removed by Mendelian analysis and thus leave a permanently pure stock.[1]

[1] "One of the greatest advances to be claimed for the work is that it should induce raisers of seed crops especially to take more hopeful views of their absolute purification than have hitherto prevailed. It is at present accepted as part of the natural perversity of things that most high-class seed crops must throw "rogues," or that at the best the elimination of these waste plants can only be attained by great labor extended over a vast period of time. Conceivably that view is correct, but no one acquainted with modern genetic science can believe it without most cogent proof. Far more probably we should regard these rogues either as the product of a few definite individuals in the crop, or even as chance impurities brought in by accidental mixture. In either case they can presumably be got rid of. I may even go further and express a doubt whether that degeneration which is vaguely supposed to be attendant on all seed crops is a physiological reality. Degeneration may perhaps affect plants like the potato, which are continually multiplied asexually, though the fact has never been proved satisfactorily. Moreover, it is not in question that races of plants taken into unsuitable climates do degenerate rapidly from uncertain causes, but that is quite another matter * * *. If the rogues are first crosses the fact can be immediately proved by sowing their seeds, for segregation will then be evident. For example, a truly round seed is occasionally, though very rarely, found on varieties of pea which have wrinkled seeds. I have three times seen such seeds on my own plants. A few more were kindly given me by Mr. Arthur Sutton, and I have also received a few from M. Philippe de Vilmorin—to both of whom I am indebted for most helpful assistance and advice. Of these abnormal or unexpected seeds some died while germinating, but all which did germinate in due course produced the normal mixture of round and wrinkled, proving that a cross had occurred. * * * I anticipate that we shall prove the rogue throwers to be a class apart. The pure types then separately saved should, according to expectation, remain rogue-free, unless further sporting or fresh contamination occurs." (See Bateson, W. "Genetics." Popular Science Monthly, vol. 79, no. 4, October, 1911, pp. 319–321.)

No breeder would deny, of course, that varieties or lines of descent differ in the production of degenerate individuals as well as in other ways. This is a feature that is often taken into account in the choice of varieties of garden crops. But this is apart from the main issue whether there are any pure lines of descent that remain uniform in all their members and never throw any rogues. To admit that further sporting is likely to occur is to abandon the claim of permanent uniformity. If the Mendelian doctrine is of practical value, it should be possible to find a permanently uniform pure-bred line of descent in some species of plant or animal, one that could be multiplied to large numbers and subjected to different conditions of existence without sporting.

What the cotton industry needs even more than the breeding of new varieties is the development of a system for preserving varieties from deterioration by removing the rogues as soon as they appear. Whether the object of uniformity is to be attained through the medium of organized efforts of cotton-growing communities, public seed-control stations, or through the activities of private breeders and seed growers, the present need is to educate the public in the importance of uniformity and the need of continued selection as a means of preserving superior varieties. To rely on the Mendelian assurance of securing permanent uniformity by pure line breeding would mean a further postponement of consideration of practical measures that are so obviously needed.

## EXPRESSION RELATIONS OF COLOR CHARACTERS.

Though color characters and others that depend directly on chemical reactions most commonly show the Mendelian form of alternative expression, two quite different relations are presented by the color characters of cotton. In hybrids between the Egyptian and the Upland types of cotton the lemon-yellow color of the Egyptian petals usually appears in plants that show a preponderance of other Egyptian characters, but very rarely in plants with distinctive Upland characters. A few hybrid plants, perhaps half a dozen out of as many thousands, have been found with the incongruous combination of Egyptian color with Upland form, but these individuals were infertile and abnormal in other respects. The combination of white petals with Egyptian characters is less incongruous and much more frequent, in some Egyptian fields about one plant in a hundred. Some of the white-flowered Egyptian plants are sterile or otherwise malformed, but many are fertile and apparently normal.

The purple spot at the base of the petals of the Egyptian cotton is inherited in quite a different manner. It is often definitely expressed in hybrid plants with white petals and a preponderance of the other Upland characters, while plants with yellow petals and

the other Egyptian characters may have a very faint spot, or none at all. Unlike the general colors of the petals, which are symphanic with other characters of the same parent and antiphanic to those of the other parent, the expression of the purple-spot character shows a much more indifferent or paraphanic relation with other characters. Even among the conjugate hybrids there is a wide range of variation in the expression of the purple spot.[1]

Nevertheless, the spot character is not without definite expression relations. In a study of the Jannovitch variety of Egyptian cotton from the standpoint of contamination with the inferior Hindi type, some plants were found that seemed to depart from the Egyptian characters only in having the spot of a paler shade of purple than usual. At first this difference was considered quite insignificant, because of the frequent variability of the spot. Even on the same plant there is often a wide difference, some flowers having a well-developed spot and others none at all. But in the autumn it appeared that all of the Jannovitch plants with the pale-spotted flowers produced only small bolls. The recognition of the fact that some of the plants had only pale spots made it possible to learn that such plants also had limitations in the size of the bolls.

The prospect of discovering such a relation by a general system of measurements of spots and bolls would have been very small in spite of the large amount of labor that would have been required. Now that the fact has been recognized, the working out of a mathematical expression of relation between the paling of the spots and the reduction of the size of the bolls might be an interesting mathematical diversion, but it seems quite unnecessary for biological interest or agricultural application. The use of the correlation lies in the recognition of the pale spot as a symptom of degenerative variation or departure from the characters of the Jannovitch type. It affords another means of guarding the uniformity of such stocks by selection.

## EXPRESSION RELATIONS OF STRUCTURAL CHARACTERS.

In the Upland type of cotton an abundance of fuzz on the seed is antiphanic to long lint but symphanic with abundant lint. If the selection of Upland cotton be directed exclusively to the production of longer lint, the fuzz tends to disappear and the lint also becomes more sparse. If abundance of lint is to be maintained, selection for length of lint needs to be restricted to plants with fuzzy seeds. The production of fuzz represents a favorable condition for the production of abundant lint. Abundant lint is sometimes found on

[1] Cook, O. F. Hindi Cotton in Egypt. Bulletin 210, Bureau of Plant Industry, U. S. Dept. of Agriculture, 1911, p. 31.

naked seeds, but this is opposed to general tendency and represents an unstable condition of expression. Later generations of naked-seeded selections have shown persistent tendencies to sparse lint in spite of repeated selection to maintain abundance.

The symphanic relation between fuzz and lint does not hold at the other end of the series of variations, for with an excessive development of fuzz the lint usually becomes less abundant. This has been shown repeatedly during the acclimatization of the Kekchi cotton, and the same tendency has appeared in experiments with seed selection in the Columbia cotton. In a series of such selections compared by Mr. Argyle McLachlan the plants that were raised from seeds with a rather thin short fuzz showed a general superiority in lint characters over those raised from seeds with the heaviest coating of fuzz. A new short-staple variety with a very high percentage of lint, recently announced by a Georgia breeder, has unusually short uniform fuzz. Seeds with too much fuzz doubtless represent a partial or complete absence of the normal specialization of the two kinds of hairs on the seed coat.

Long lint is also symphanic with narrower and more pointed forms of bolls and antiphanic to short rounded bolls. A variation toward a more rounded form of boll is seldom or never accompanied by variation toward longer lint, whereas variations toward narrower and more pointed bolls often show longer lint. This relation holds among different species and varieties as well as among individual diversities of hybrids and selected stock. The coherence of these characters is evidently biological and phyletic, unlike the ordinary correlation that exists between abundance of lint and increased diameters of bolls. The fibers do not lie extended in the bolls, but are packed about the individual seeds. It is easy to understand why more abundant lint should involve thicker bolls, but there is no mechanical requirement of longer bolls to contain the longer lint.

The practical importance of the relation between the form of the boll and the length of the lint does not depend upon its being stated in mathematical terms. The breeder has an adequate demonstration of its value when he finds himself able to predict the relative lengths of lint of different plants by simple inspection of the forms of the unopened bolls. In the great majority of cases the shorter lint will be found in the broader and more rounded bolls. Plants with pointed or tapering bolls will sometimes be found to have short lint, but it is much more rare to find longer lint in more rounded bolls.

A statistical statement of the relation would be likely to give no adequate idea of its practical importance, owing to the great variability of the factors involved. The lengths of the lint fibers differ not only on the same plant but on the same seed. Satisfactory measurements of bolls are also very difficult because of the complications

introduced by differences of angularity and taper. The shapes and sizes of bolls differ in the same variety in different places. Even in the same plant the checking of growth by drought may induce smaller and more rounded bolls and shorter fiber. But, in spite of these irregularities, familiarity with the plants usually makes it possible to distinguish at a glance those that show definite deviations from the type of the variety in the direction of more rounded bolls and shorter lint. If elaborate measurements were required to distinguish the variations, the relations of expression would have no practical value in the work of selection.

Another general relation of coherence in the expression of characters in cotton exists between the length of the lint and the number of carpels or locks in the bolls. The Sea Island, Egyptian, and other long-linted types of cotton have fewer locks than the short-staple Upland varieties. The long-staple cottons have three or four locks, but in short-staple cottons a considerable percentage of 5-locked bolls is a regular feature. The same relation is found in hybrids between long-staple and short-staple cotton. Egyptian-Upland hybrid plants that have any 5-locked bolls seldom have long lint, a fact first remarked by Mr. Rowland M. Meade. Likewise among variations of Upland cotton, plants with longer lint generally show smaller proportions of 5-locked bolls.

An analogous relation in the expression of characters not directly connected or commensurable with each other has been reported by Worsley in Capsicum pepper. It was found possible to judge the taste of the fruits from their size and shape. Worsley says:

> I do not claim to have tasted every variety of alleged species of Capsicum, but I have tasted a great number, and I have invariably found that the "hot" tasting properties associated with cayenne pepper are confined to those Capsicum fruits which have pointed apices, the degree of heat varying inversely with the size of the fruit, the smaller being the hotter. Conversely, those fruits with blunt apices are known as "mild" Capsicums, and among these mild fruits the degree of mildness varies with the size, the largest being the mildest.[1]

## TWO CLASSES OF HYBRIDS.

The literature of heredity abounds in general statements regarding hybrids. Some writers hold that hybrids are more variable than the parent stocks and others that they are more uniform; some that hybrids are more vigorous, others that they are weaker. But all such generalizations are misleading for the reason that there are two distinct classes of hybrids, governed by different physiological principles inherent in the very nature of the reproductive processes.

Instead of revealing the existence of character units or determinant particles, the study of the formation of germ cells has

[1] Worsley, A. Variation as Limited by the Association of Characters. Journal, Royal Horticultural Society, vol. 36, pt. 3, May, 1911, p. 599.

thrown light on another side of heredity by making it possible to understand the sharp contrasts so frequently found between the first generation of hybrids and the later generations. The cytological discoveries of recent decades have given an entirely new view of the process of conjugation.

Instead of being concerned merely with the union of the germ cells, conjugation has to do with the entire life history of the new organism. Its function is not merely to cause growth to begin but to conduct the whole course of development. The process of conjugation that begins with the union of the germ cells does not come to an end until the new generation has reached the stage of forming its sex cells. It is only the reproductive tissues that can be said to pass through conjugation and go back to the state of simple cells. All the cells that compose the bodies of the higher plants and animals represent specializations of double, conjugating cells, formed by the subdivision of the original double cell or zygote.

In other words, the so-called first generation of a hybrid develops while the conjugation begun by the union of the germ cells is still in progress. What is called the second generation is really the first that represents the results of a complete conjugation. In recognition of these differences the first generation, developed before the original conjugation is completed, has been described as the conjugate generation, while the generation formed by germ cells that have passed through conjugation has been called perjugate.[1]

The results obtained with hybrids in the first generation afford no indication of what is to be expected in the later generations. Nothing could appear more deceptive than the behavior of the first generation of hybrids, until it is recognized that the later generations represent an entirely distinct biological phenomenon. Failure to recognize the fundamental differences between the generations of hybrids is responsible for many vain efforts in breeding.

Conjugate hybrids of cotton are not only much more vigorous than the parental stocks but usually more uniform and more productive, thus arousing lively hopes of developing superior hybrid varieties. But in the perjugate generations none of these promises are fulfilled. The uniformity of the conjugate generation gives place to a multifarious diversity. Many plants are weak and sterile, and many others produce only short and inferior lint. For reasons to be explained in later chapters there seems to be little prospect of breeding hybrid varieties to be propagated by seed. To enable the superior conjugate hybrids to be used for purposes of production will require the development of special methods of producing the seed or methods of vegetative propagation.

[1] Cook, O. F. Mendelism and Other Methods of Descent. Proceedings, Washington Academy of Sciences, vol. 9, July, 1907, p. 195.

## INTENSIFIED EXPRESSION OF CHARACTERS IN CONJUGATE HYBRIDS.

In addition to different combinations and intermediate degrees of the parental characters, hybrids often show a much wider range of expression, beyond either of the parent varieties. In such cases the characters may be described as extraparental, or outside the parents, instead of interparental, or between the parents. Two forms of extraparental expression may be recognized. A character shown in a higher degree than in either parent stock may be described as intensified. A character that disappears or is expressed in a less degree than in either of the parents is said to be suppressed.

One of the most frequent examples of intensified expression in cotton is the appearance of a bright-green color in the fuzz of hybrid seeds even when the parents show only a slight trace of colored fuzz or none at all.[1]

Other examples of extraparental expression are afforded by the nectaries of the involucre of the cotton plant. The full number of nectaries is three, though their occurrence is usually very irregular in both the Upland and the Egyptian types of cotton. But among the hybrids some plants are found with a full complement of three nectaries on all of the involucres, while other plants have very few nectaries or none at all.

The lint characters of hybrids also show intensification beyond the parental standards. In hybrids between Egyptian and Upland cotton there is not merely a dominance of the long-lint characters of the Egyptian parent, but the hybrid lint is usually distinctly superior in length and strength to the lint of Egyptian cotton grown under the same conditions.

The hybrids differ from the parent stocks in having a greatly increased constitutional vigor, as well as in details of expression of the various characters. This increased vigor is manifested both in the larger size of the hybrid plants and in their greater ability to withstand unfavorable conditions that would restrict a full expression of the lint characters in the parental types. It is conceivable, therefore, that the greater length of lint in the hybrids may be due to their increased powers of adaptation to adverse conditions rather than to any more special change of the lint characters.

It has been noticed that the inequality of lint between hybrids and Egyptian plants is greater under very adverse conditions and less under more favorable conditions. This is in agreement with the general fact that the increased vigor and fertility of the hybrid plants is

[1] Cook, O. F. Reappearance of a Primitive Character in Cotton Hybrids. Circular 18, Bureau of Plant Industry, U. S. Dept. of Agriculture. 1908. See also Suppressed and Intensified Characters in Cotton Hybrids, Bulletin 147, ibid., 1909, p. 8.

more obvious in places where the growth of the plants is restricted. Where conditions favor a very luxuriant growth of the Egyptian cotton the forms of the Egyptian and hybrid plants become more similar, so that it becomes more difficult to recognize and rogue out the hybrids. Under ideal conditions that would permit a full expression of the lint characters of the Egyptian cotton, the length of the lint of the hybrids might no longer appear to be intensified. But if this view be taken, a very high estimate must be placed upon the increased vigor of the conjugate hybrids as a factor of adaptation, for the lint of conjugate hybrids has been distinctly superior to the lint of the pure Egyptian plants in nearly all of the experiments that have been made.

The enlarged nectaries, green fuzz, and many other divergent characters that appear in the second and later generations of cotton hybrids must be considered as representing another form of intensification. They do not appear to be results of greater vigor or more effective adaptation but may be in the nature of reversions. A full development of the involucral nectaries is a less specialized condition than a partial suppression of nectaries. Likewise, many of the primitive, unimproved types of cotton have green fuzz similar to that of the hybrids.

The reversion of hybrids to green fuzz may not involve any very serious disturbance of heredity, if it can be accomplished by a mere suppression of the parental characters. If the relations of the parental characters are antagonistic, so that neither of them can come into expression, the course of development is halted at an earlier stage. It may often be difficult to distinguish between suppression and intensification, for an abnormal development of one character may be due to the suppression of some normal inhibitory adjustment, as shown in the tendency of castrated animals to grow to larger size than normal individuals. Thus, a result which in some cases is due to increased vigor may arise in other cases from sterility or some other abnormal condition. The expression of one character represents a condition, favorable or unfavorable, for the expression of another, each character representing a stage in the sequence of development.

That hybridization often has the effect of inducing wholesale reversion or reappearance of ancestral characters has been recognized in such well-known cases as the blue hybrids produced by crossing two white varieties of pigeons, the redder plumage of hybrid fowls, and the reappearance of the incubating instinct in crosses between two nonsitting varieties. Such atavistic reappearances of more primitive characters seem to be almost as frequent as other methods of adjusting the expression relations of contrasted parental charac-

ters in hybrids, and as worthy of being taken into regular account in interpreting the phenomena of hybridization.[1]

## DEGENERATION IN PERJUGATE HYBRIDS.

The utilization of the increased vigor and fertility of hybrids is a difficult problem because the intensified condition is only temporary. Hybrids between Upland and Egyptian cotton are often very uniform in the first generation, as uniform as the parent stocks, or even more so. But in the second and later generations this uniformity disappears and is not recovered. For three or four generations some individuals continue to show resemblance to the superior first-generation hybrids, but progenies of such plants are diverse, like those that are obtained from the so-called heterozygotes in a typical Mendelian hybrid. The other plants that correspond roughly to the homozygotes of Mendelism return to the expression of the characters of the parental stocks in different degrees and combinations. In many cases there is an almost complete return to the Upland or the Egyptian characters, but such "extracted" individuals very seldom, if ever, attain the parental standards of expression of the lint characters. The Uplandlike plants do not have as good lint as the Upland parent, and the Egyptianlike plants are similarly inferior to the Egyptian parent.

All of the plants that have been selected for the desired combination of Upland vegetative characters and Egyptian lint characters have yielded utterly diverse progenies. In some of the best progenies detailed comparisons were made to see whether any of the desirable individuals were alike, but without finding even two of them with any close similarity in external characters.

In addition to the hybrids that might be supposed to correspond to the Mendelian classes, another group might be recognized to contain the abnormal or aberrant individuals, those that show extraparental expression of characters. Such deviations appear in many organs of the plant, if not in all, including the habits of growth and the system of branching, the form, texture, and hairiness of the leaves, and in all of the recognized characters of the involucres, bolls, seeds, and lint. Many of the aberrant plants produce very little cotton and some are completely sterile. These abnormalities do not appear in the conjugate generation, where extraparental expression is limited to unimportant details, like the greener color of the fuzz. As already stated, the conjugate generation is usually less diverse

[1] Four general reactions of expression may be recognized in first-generation hybrids. In some hybrids there is a blended or combined (mixophanic) expression of the contrasted characters. In other cases one of the parental characters is suppressed (hypophanic), allowing the opposed character to appear as dominant (epiphanic). When both of the parental characters are suppressed, so that a more primitive character appears, the result may be described as reversive or atavistic expression (palimphanic).

than the parental stocks, while the perjugate generations are much more diverse than the parental stocks because of the presence of the intermediate and extraparental expression of characters.

In the hybrids between the Upland and Sea Island types of cotton made originally by Dr. H. J. Webber and bred by progeny-row methods for about 10 generations, somewhat better results have been secured, either because there is more affinity between the Upland and the Sea Island cotton or because the experiments have been carried on for a longer period. In a series of these hybrids planted at San Antonio, Tex., in the season of 1911, the uniformity was sufficient to show some general consistent differences between the progenies, both in habits of growth and in lint characters. There were none of the very abnormal or completely sterile individuals that often appear among the Egyptian hybrids, yet none of the progenies showed any such uniformity as would be demanded in a commercial variety. The lack of uniformity was particularly apparent in the lint characters. Moreover, the lint no longer showed any advantage from crossing with the superior Sea Island cotton. It was distinctly inferior to that of some of the Upland varieties planted in the same place.

The contrast in behavior between the first generation of hybrids and the later generations shows that two different factors or results of hybridization must be recognized. The vigor or increased efficiency of expression in the first generation is followed by a reaction toward weak or inefficient expression in the later generations. These not only fail to maintain the superiority of the first generation, but fall below the standards of the parent varieties.

One way of describing the results is to say that hybridization undoes the work of selection. The uniformity of expression established in parental stocks by selective breeding is lost, and there is a return to an ancestral condition of indiscriminate diversity. But even this may not represent the entire possibilities of change, for many of the aberrant features shown in the second and later generations of hybrids lie far outside the range of the parental characters, and some of them are so abnormal that they can hardly be taken as simple reversions.

One of the most frequent abnormalities is an enlargement of the involucral bracts. This might be considered as a return to an earlier state when these organs were less specialized. Enlargement of the bracts is frequently accompanied by abortion of bolls. The difference between the fertile and the sterile involucres is often apparent on the same plant. Two involucres of a perjugate (second generation) hybrid between Mit Afifi Egyptian cotton and the Willet Red Leaf variety of Upland cotton are shown in Plate II, right-hand figures (*B*). The enlarged sterile involucres were borne on longer pedicels

and were of a lighter and more greenish color, while the small involucres that produced bolls retained the deep reddish purple color of the Upland parent. A similar inequality in the size of the bracts and the elongation of the petioles was found in another perjugate hybrid between Mit Afifi and Triumph, as shown in the left-hand figures (A) of Plate II. In this case there was no difference in color, but the enormous development of the bracts of the sterile involucres, with their coarse texture and long incurved teeth, afforded a striking contrast.

If these abnormalities be considered as examples, intensification may be said to abound in the later generations of hybrids as well as in the first. But in the later generations intensification is no longer accompanied by increased vigor and fertility. It is more often combined with weakness and sterility. The vigor of hybrids does not seem to depend merely on the fact that different characters are present in transmission, but rather on some factor of tension or stress involved in the expression of divergent or contrasted characters. It is easy to understand that the expression relations of the characters would not be the same in the first generation, before the protoplasm derived from the diverse parents has completely united, as in later generations, after the protoplasm has passed through one or more complete conjugations. To make the heterozygote class of the second generation equal to that of the first it would be necessary to assume an absolutely complete segregation of the characters which even the typical examples of Mendelism do not indicate. The final result of crossing the different types is not a constructive improvement or combination of characters but a destructive disturbance of the normal processes of heredity.

It is true that natural species are often found with characters more or less intermediate between those of other species, and many writers have inferred from this fact that hybridizing is one of the natural means of producing new species. But there is very little in the way of direct evidence for the production of new species or even stable varieties by hybridization. The few cases where apparently constant forms have been secured by crossing different species are more reasonably ascribed to peculiarities of reproduction such as parthenogenesis, polyembryony, or amitapsis, or to the exclusive survival of embryos that represented certain combinations of characters. Investigators of Mendelian hybrids have reported cases where one of the homozygote classes failed to develop. If both of the homozygote classes disappeared the heterozygotes would be left as an apparently stable intermediate group.[1]

[1] See Castle, W. E., and Little, C. C., "On a Modified Mendelian Ratio among Yellow Mice," Science, n. s., vol. 32, p. 869.

When hybrids do not breed with each other but are allowed to cross back on one of the parental types the effects of degeneration are not so obvious. The degenerative tendencies that are manifested when the hybrids are bred among themselves are partly counteracted by the effect of the stimulation obtained by crossing with a pure type. This difference was noticed many years ago by the German botanist, Berthold Seemann.

In writing of the inhabitants of the Isthmus of Panama, Seemann made the following statement:

> They [the half-castes] are weak in body and are more liable to disease than either the whites or other races. It seems that as long as pure blood is added the half-castes prosper; when they intermarry only with their own colour they have many children, but these do not live to grow up, while in families of unmixed blood the offspring are fewer, but of longer lives. As the physical circumstances under which both are placed are the same, there must really be a specific distinction between the races and their intermixture be considered as an infringement of the law of nature.[1]

Similar results have been secured in a series of experiments with dilute cotton hybrids. When a pure type, Egyptian, Hindi, or Upland, is crossed with a hybrid the resulting progenies are much more diverse than the first-generation hybrids between the same types. Plants representing only one-quarter of Upland or Hindi blood and three-quarters Egyptian often depart more widely from the normal Egyptian characters than any of the half-blood hybrids in the first generation. The tendency to intensified or extraparental expression of characters in second-generation hybrids is also manifested among the dilute hybrids. Taken as a whole, the dilute or quarter-bloods produced by crossing the hybrids back on one of the parent stocks are distinctly superior to the second generation of the hybrids. At the same time they are distinctly inferior to first-generation hybrids because of the many aberrant individuals. Their status may be described as intermediate between the first generation of ordinary hybrids and the second generation.

If it were necessary to breed from the hybrids, it would evidently be better to combine them with the parent varieties than to breed them with each other, as Seemann inferred. With cotton, however, there is no occasion to use hybrids for breeding in view of the fact that the later generations are inferior to the first. By crossing hybrids of the second or later generations back on one of the parent stocks it might be possible to secure some superior individuals, perhaps as good as first-generation hybrids, but the greater diversity would bring the average far below the first generation. This disparity seems to be less with corn hybrids than with cotton. Nor is it obvious as yet in the series of bovine hybrids produced by Mr.

[1] Seemann B. Narrative of the Voyage of H. M. S., *Herald*, vol. 1, 1853, p. 302.

A. P. Borden, of Pierce, Tex., between several American and East Indian breeds.

If it became possible to apply vegetative methods to the propagation of cotton, the dilute hybrids might be worthy of further attention, since they afford a means of combining two of the effects of hybridization—vigor of growth and intensification of special characters. That hybrids may be grown from cuttings was shown at Bard, Cal., in the season of 1911. The plants thus obtained were very vigorous and productive, and the bolls were even larger than those of the overwintered parent individuals from which the cuttings were taken and also larger than those of other first-generation hybrids raised from seedlings, as shown in Plate III. The two bolls at the top of Plate III represent the parent plant, the others a plant grown from a cutting.

## INTENSIFIED CHARACTERS IN SELECT STRAINS.

Darwin and many later writers have ascribed to selection a more active power of producing changes of characters than the facts of breeding seem to justify. The improvements effected by breeders are supposed to represent changes of the same nature as those that lead to the evolutionary development of new characters. In reality, however, the analogy is not complete. The difference becomes apparent when the nature of the processes is more carefully considered.[1]

The breeder who works through selection alone does not undertake to change the characters of any particular plant or animal. Selection is merely a way of making use of differences that are found already in existence. The lines of descent that show the highest expression of a desired character are preserved and propagated, the other lines discarded. To replace inferior lines by superior lines is a practical improvement quite independent of any change of characters in the select individuals or their descendants. Selection maintains the expression of the preferred characters at a higher average because the inferior lines are eliminated and no longer figure in the average. Such changes are mathematical instead of biological and afford no reason for supposing that selection has in itself any power to create new characters or even to alter expression. The breeder finds superior individuals and uses them to propagate a superior group. Selective improvement is a process of substitution of groups, not of transformation of characters.

The skill of the breeder lies in his ability to distinguish minute differences and thus to separate more successfully the lines of descent that show the largest and most uniform expression of the desired

[1] Cook, O. F. Methods and Causes of Evolution. Bulletin 136, Bureau of Plant Industry, U. S. Dept. of Agriculture. 1908.

characters. It may be easier to find the desired type by a careful following of the lines of descent than by wandering at random through an endlessly diverse population. The skillful breeder may secure more striking and valuable results with relatively small numbers than less discriminating observers would obtain from much more extensive material. Some breeders begin by hybridizing to induce a wider range of variation than the natural groups afford, but many of the variations shown by hybrids can be found in the parent stocks if a thorough search be made. Hybridizing is of doubtful value with an open-fertilized, seed-propagated plant like cotton, because of the greater difficulty of securing uniform expression of characters after hybridization has occurred.

Without ascribing to selection any direct effect in changing characters, the possibility that some changes may be induced indirectly should be recognized. The methods of propagation that are applied to select groups may be responsible for some of the results that have been ascribed to selection. Selection is usually accompanied by restriction of descent to a few ancestral lines. The range of crossing is narrowed more and more as selection becomes more discriminating and efficient, until the method of pure-line breeding is reached. This calls for the narrowest possible limitation of ancestry, by in-and-in breeding or self-fertilization.

The chief object of restricted descent is to secure a uniform expression of desirable characters in the progeny, but this is not the only effect of narrow or line breeding. The evil results that often arise from consanguineous marriages have been recognized since very early times and by very primitive peoples, and similar results are known to follow with many species of plants and animals. Inbred strains are preserved only by persistent weeding out of degenerate individuals.

Two principal kinds of injury from narrow breeding may be distinguished, though they are likely to be found together. One is a lack of constitutional vigor, usually manifested in smaller size or diminished resistance to disease or to unfavorable conditions. The other is an increase or intensification of any abnormal feature or tendency of the parents.

Any lapse from normal heredity in the parent is likely to be repeated in at least a part of the descendants. Thus, the Arabs of Palestine consider it undesirable to breed from a horse having any of the skin white, however small the area, for they say that the spot is likely to be much larger in the foal. The tendency of any abnormal characteristic to reappear is greatly increased when it is represented in the heredity of both parents, which is more likely to occur when narrow or line breeding is being practiced. Albinism and other

changes of color are among the most frequent of these degenerative variations that appear in groups subjected to narrow breeding.

When one of the degenerate variations of a select stock happens to coincide with an object that is being sought by breeders it is only natural to look upon the result as a direct effect of selection. A seedless apple or other degenerate variation is likely to be hailed as a triumph of selection, even when there has been no attempt to produce that particular variation. The chances of securing such a variation as seedlessness can be increased, no doubt, by propagating from individuals that have fewer seeds, but the increase of the abnormality in any particular individual can hardly be ascribed to selection. The steps have to be taken by the plants themselves, not by the operator. All that can be done is to find a seedless individual and propagate it from cuttings.

The truth is that we have no means of causing any desired variation to appear, by selection or otherwise. All that we can do is to take advantage of the general fact that variations do appear and seek for the most desirable. There are ways of inducing variation by changing the environment, by crossing, or by degeneration through narrow breeding, but these methods do not assure us of any particular result; they only increase our chances of finding what we want. As in throwing dice or dealing cards, the chances are against any particular combination being formed in any limited number of cases. The larger the number of combinations the greater chances that some of them will prove desirable. Selection is the art of finding the combinations after they have occurred, but it is not the art of making combinations. That more desirable combinations or degrees of expression may appear in selected stocks is not to be ascribed to selection, except indirectly, in the same way that the undesirable, degenerate variations must also be considered as results of the condition of inbreeding that selection induces. The undesirable variations are vastly more numerous than those that are superior or even equal to the parental type.

Whether losses of color or of other normal characters represent simply failures of expression or more deep-seated injuries of the mechanism of transmission is not known. The Mendelian inheritance of such variations has been taken as proof of alternative transmission, but alternative expression serves as well to explain the mathematical relations of Mendelism and also accounts for the frequent cases of reversion or reappearances of characters, even after they have been suppressed for many generations. To explain reversion, Mendelian writers have suggested that such characters may be due to two or more factors that have been transmitted separately and then reunited by crossing. But this factorial explanation of latency can hardly be brought into action when reversions take place without

crossing. Recourse must then be had to the idea that the character or factor has been recreated as a mutation.

The fact that so many of the differences between select varieties show Mendelian inheritance may be taken to indicate that the suppression of characters is a very frequent occurrence among our domesticated animals and plants. Similar variations occur, of course, in wild species, but they seem to be much more rare, and seldom able to persist. The white, black, brown, or yellow colors that distinguish the domesticated varieties of mice, rats, guinea pigs, or rabbits, the characters that afford the materials for so many Mendelian experiments, are not paralleled by any corresponding differences among the related wild species. It is the same way with plants. The cultivated varieties differ largely by the absence of some of the characters that all of the wild types have. Thus no wild or unselected stocks of cotton are known to have the shortened "cluster" type of fruiting branches, which represents one of the most frequent of mutative variations of select strains.

The differences that distinguish natural species are not like the sharply contrasted unit characters that distinguish mutations, but are of a much more general and indefinite nature. Nor do hybrids between natural species vary in the same definite ways as hybrids between select, uniform varieties. Instead of merely different combinations or intermediate expression of the characters of the parent individuals, interspecific hybrids generally show a much wider range of variation, both above and below the standards of the immediate parents.

It usually takes several generations of domestication for wild species to break up into various colors and other varietal differences, but when these changes occur they often follow remarkably parallel lines. It is possible, apparently, to secure cluster variations in any type of cotton that is subjected to selection. The same tendency to abnormal shortening of internodes also appears in many other plants, as witness the "bush" varieties of squashes, peas, and beans.

Aberrations of color characters are frequent in plants as well as in animals. They are usually confined to the flowers, though variegated leaves also occur, probably in all the families. Complete albinism is an impossibility among the higher plants, because the albino individuals starve to death in the seedling stage as soon as the supply of nourishment stored in the seed is exhausted. The absence of chlorophyll prevents the formation of starch and thus inhibits development. Yet many albino seedlings have been seen, both in cotton and corn. In such cases it is certain that the variation is not in the nature of a reversion, for no albino ancestor could have lived or produced seed.[1]

[1] That albino plants would be able to live and reproduce like albino animals, if they could nourish themselves, was indicated by an instance, called to my attention, at

It has to be recognized, therefore, that domesticated plants and animals are subject to certain forms of negative variation, representing losses or suppressions of characters. The progressive increase or intensification of a negative, degenerative character under conditions of selection should not be mistaken for a positive. constructive development of a new character. The possibilities of selection are by no means the same in the two cases. Lintless varieties of cotton would be very easy to develop by selection, for all types of cotton show frequent variations toward reduction of lint. Even without any such selection, plants with no lint at all have appeared. All the selective effort has been applied to the increase of the length and abundance of lint, and yet no marked increase or intensification of these characters seems to have occurred. Unselected Mexican and Central American varieties of Upland cotton have lint as long or longer than any corresponding varieties in the United States.

There are hundreds of inferior mutations with short or sparse lint to one that is superior to the parental type, or even equal. Though continued selection is necessary to preserve the uniformity of varieties of cotton and maintain the length of the lint, there is nothing to show that selection can produce further elongation. It is no more reasonable to say that variations toward longer lint are caused by selection than to say that selection has caused the much more frequent variations toward short or sparse lint. If the question were to be decided by an average of the variations in comparison with the parent stock, the conclusion must be that selection has an adverse effect.

The idea that it is possible by dint of selection to induce new variations in any desired direction undoubtedly has served as a great encouragement to breeders. It is responsible for some brilliant successes in finding superior types, and also for some costly failures, where something was sought that perhaps did not exist. If a desired change is in the nature of a suppression or breaking down of a normal coordination or specialization of parts, the conditions of selective inbreeding may be expected to favor the increase or intensification of such a negative or degenerative variation. But if a positive character is required, such as an increase of vigor or fertility, or

Somerton, Ariz., in July, 1909, by Mr. Rowland M. Meade. This was an albino bud mutation of a watermelon vine that grew out into a large branch several feet long, supported, no doubt, by its attachment to the green parent plant. All of the vegetative parts of the albino branch were pure white. The leaves were never fully expanded like those of the normal branches. The albino branch bore a single fruit in October, about 8 inches in diameter and of a short oval form. The rind was a very pale yellowish green, somewhat blotched with slightly darker greenish, but still quite pale. The flesh was pale greenish under the skin and pale pinkish within, with a solid white center. The taste was insipid and disagreeable. The seeds were saved to see whether they would germinate and produce albino seedlings, but were accidentally lost. The presence of the green color in the fruit may be taken to indicate that this character did not cease to be transmitted, though it had failed to appear in any of the vegetative parts of the branch.

the largest expression of some special feature or of a specialized organ or function, the task of selection is to find the superior type and then to maintain a uniform stock by removing all defective individuals. Selective inbreeding seems to intensify only the negative characters. Positive characters are intensified by crossing.

## INTERMEDIATE EXPRESSION OF METAMERIC DIFFERENCES.

Abnormalities are of interest in the study of heredity. To understand what happens when the mechanism of heredity becomes deranged is to gain a better idea of the normal processes. Our knowledge of the functions of the internal organs of the human body has been gained very largely through the study of diseased conditions. Many kinds of abnormalities have been described and classified, the study of such phenomena being recognized as a special branch of biological science, called teratology.

One type of abnormality of very frequent occurrence in the cotton plant may be ascribed to an intermediate expression of characters that normally distinguish the different kinds of metamers or internodes that make up the bodies of plants. With many plants a section of the stem with its leaf or leaves may be capable of an independent existence, as in the case of the cotton plant. The change of characters required in passing from vegetative to floral parts is normally quite abrupt. When there are only partial or gradual changes of such characters the results appear abnormal.

In all normal cotton plants the leaves of the fruiting branches and the bracts that compose the involucres of the flowers are entirely different structures, quite unlike in size and shape, as may be judged from a comparison of figures 3 and 4. But cases are often found where the normal specializations of leaves and bracts are not reached and abnormal organs appear, representing intermediate stages between leaves and bracts (fig. 5). In some of the bractlike leaves the petiole is only partly suppressed (fig. 6). It often happens that the two sides are unequally affected, the petiole being suppressed on one side but not on the other. One stipule is united with the blade while the other is separated, often for a considerable distance. Such leaves are often distorted, or even torn, by the unequal growth of the two sides, as in the example shown in figure 7. Sometimes there is a reduction in the size of the leaf without a change of form or texture (fig. 8).

In leaflike bracts the form and texture may be normal, but without a proper union of the parts (Pl. IV). Or the parts may be properly united at the base and yet lack the normal specialization of marginal teeth (fig. 9). Sometimes the middle division, representing the blade of the leaf, is much longer than the lateral divisions that represent the stipules (fig. 10).

Such failures of the mechanism of heredity to maintain the normal contrast between leaves and bracts are usually accompanied by an inability to produce the normal structures of the flower and fruit. The flower buds of abnormal involucres are usually aborted. Sterility seems to accompany an intermediate expression of characters in the parts of the individual plant, as well as intermediate expression in hybrids between remotely related species.

FIG. 3.—Leaf of fruiting branch of Egyptian cotton. (Natural size.)

The whole series of "cluster" varieties of cotton shares the tendency to abortion of the buds. The cluster habit represents a failure of the normal differentiation between the internodes of the fruiting branches and those that form the pedicels and involucres of the flowers. The branch internodes are shortened as well as the floral internodes. The leaves of such branches are more bractlike. while the bracts are more leaflike. Intermediate forms of leaves and bracts are

much less frequent in the Upland type of cotton than in the Egyptian, but sometimes occur (fig. 11). Deeply divided involucres are often met with in cluster varieties (Pl. V).

Though such losses of normal specialization usually occur as definite mutative changes of characters, there are also indefinite variations of the same kind. The outer bract of the involucre often has an intermediate form while the others show the normal specializations (fig. 12). These cases are of interest as evidence of a power of spontaneous readjustment in the mechanism of heredity. A fruiting branch that has produced an abnormal internode may afterwards produce normal internodes. An example of this is shown in Plate VI, which represents leaves from three successive internodes of a fruiting branch of Egyptian cotton. The first leaf is of the normal form, with a 3-lobed blade and small stipules. The second leaf has one of the stipules distinctly enlarged and bractlike, while the blade is simple. The third leaf is like the first, with normal, 3-lobed blade and with the stipules only slightly enlarged.

FIG. 4.—Involucre of Egyptian cotton with normal bracts. (Natural size.)

A power of readjustment is also shown when normal flowers, fruits, and seeds are produced in connection with abnormal leaves and bracts. In one Egyptian variety called "Dale," as grown in California, nearly all of the bracts and leaves of the fruiting branches are abnormal. This variety is also subject to wholesale abortion of buds and bolls. Yet most of the plants are able to produce small crops of seed.

Another class of metameric hybrids is shown in intermediate expressions of the characters of the two types of branches. The abnormal fruiting branches, instead of being slender and horizontal, keep a more upright position and become thicker than the others. Such branches usually abort all of their buds. When bolls are produced they are usually small and misshapen and have many abortive seeds. Plants that fail to develop normal fruiting branches have

a more upright fastigiate habit of growth and usually become taller than other plants in the same rows. At Del Rio, Tex., in September, 1911, it was noticed that abnormal plants in the Durango variety usually had greener stems and bracts than normal plants and either coarser or finer teeth on the bracts. But some of the abnormal individuals that had most of the bolls and seeds abortive had longer and stronger lint than normal plants in the same rows. This could be ascribed, at least in part, to the fact that very little fruit was pro-

FIG. 5.—Abnormal bractlike leaf of Egyptian cotton subtending a nearly normal involucre. (Natural size.)

duced. Plants that bear a small crop are less liable to checking by drought or other unfavorable conditions.

The occurrence of abnormal branches, internodes, leaves, or bracts is not a matter of scientific interest alone, but is to be considered in selection. It becomes possible to judge by careful inspection of a plant whether its expression relations are definite and well established or liable to vary. Indications of uniformity may be given by the many internode individuals of a plant as well as by the indi-

vidual plants of a progeny row. Thus at Bard, Cal., in the season of 1911, a plant of Egyptian cotton with numerous abnormal bracts but no other obvious divergence from the characters of the Yuma variety was found on closer examination to have seeds much like the Hindi cotton. There was no fuzz, and the lint retained the length and color of the Egyptian cotton, so that it would have been easy to overlook the other differences if the abnormal bracts had not been noticed.

FIG. 6.—Bractlike leaf of Egytian cotton, with the blade and petiole reduced and the stipules enlarged. (Natural size.)

**SIMULTANEOUS CHANGES OF EXPRESSION OF DIFFERENT CHARACTERS.**

The emphasis given to the idea of characters as independent units tends to obscure another fact of general importance in practical breeding. Independent transmission of characters implies the occurrence of definite variations in single characters, leaving all the other features the same. In reality, such independent changes of single characters occur very seldom, if at all.

The nature of the mechanism of expression is such that a definite change in one character usually involves changes in many other characters. A change of expression does not seem to represent merely a choice among many independent units, but a choice among whole sets of characters

as represented by different ancestral individuals. A close resemblance to a particular ancestor in one feature is likely to be accompanied by resemblances in other features or traits of character. The descendants form a continuation of the ancestral network of descent, sometimes on the same paths and sometimes on intermediate courses. Each plant or animal has its individual characters as well as its individual experience with the environment. As Goethe said: "Nature knows only the individual."

It may be better to think of characters as paths followed by individual ancestors than to attempt to conceive of them as represented by discrete particles existing in the protoplasm. As a species represents a natural entity, because its members breed together in a network of descent, so the characters of the individual plants and animals seem to have a continued existence because of their repeated expression in the lines of descent. The characters are like the threads of different colors that appear on the surface of a woven fabric, only to be lost again as the pattern changes. The same thread returns, but not the same material. The pattern is repeated, but on another part of the cloth. The pattern is only a method of arranging the material. Apart from the fabric itself, there may be nothing to represent the pattern, except the design in the mind of the weaver.

Uniformity among the members of a variety means that each individual follows the same course of development. If any individual wanders from the path with respect to one character it is more likely to continue on a different route during its subsequent development. There is a sequence in the determination of the characters, the expression of one character constituting a more favorable or less favorable condition for the expression of another. With characters standing in such relations to each other, it is easy to see why correlations, coherences, and simultaneous variations should occur. No such flexibility of expression relations would be expected if the characters were independent units, to be varied only by alternative transmission.

That the permanence of ancestral traits should suggest the idea of characters as separate entities is easy to understand on the basis of physical analogies. But notwithstanding the antiquity of the idea of independent character units, no direct evidence of the existence of such entities has been adduced. Instead of being a discovery of modern science this idea may be traced back far beyond Weismann and Darwin to the evolutionary theories of the Sicilian Greek philosopher Empedocles and his Roman disciple Lucretius. These ancient writers described the parts of animals as originating independently and afterwards finding harmonious combinations by a process of gradual adaptation. The idea was doubtless suggested

by the mythical monsters whose existence was credited in ancient times: Centaurs, satyrs, cyclopes, hippocampi, bucephali, etc.

Our modern theories do not contemplate the combination of characters of such radically different types, but they give us no better reasons for holding that characters are separate entities. The ancient and modern theories are also alike in failing to take into account the existence of species, and the normal diversity of members of specific groups. With such an inheritance of diversity it seems to be easier to vary in several characters at once than to change the expression of one character without disturbing the others.

Fig. 7.—Bractlike leaf of Egyptian cotton, with the stipule united to the blade and the potiole suppressed on one side but not on the other. (Natural size.)

It is convenient for many scientific purposes to describe and discuss characters as though they had an independent existence, in the same same way that navigators treat the lines of latitude and longitude, but the convenience of such analogies affords no assurance of actuality. As well might we expect to find the geographical parallels marked by rivers or mountains. Any analogy that aids investigation is justified by the assistance it affords, but scientific progress is often hampered by holding too long to misleading analogies. It may be that we can form no conception of the workings of heredity without some theory of characters as localized particles, but neither has it been possible to frame any adequate conception by assuming the existence of such particles. To maintain and arrange the particles would require some very effective agency of coordination which no system of independent, separately transmitted units would supply.

Whatever may be the cause of simultaneous changes of expression relations, it is of practical importance in agriculture to recognize the fact and use it as an aid in detecting and eliminating variations that would otherwise destroy the uniformity of select stocks. The agricultural value of superior varieties of cotton and many other agricultural

plants depends upon the possibility of maintaining uniformity through many generations. It is quite as important to preserve the uniformity of superior varieties as to develop such varieties in the first place. Indeed, it may be worse than useless to develop and distribute highly selected types of cotton if uniformity is not to be preserved by continued selection, for the degenerate variations of highly bred stocks often fall below the average of ordinary varieties.

FIG. 8.—Bractlike leaves of Egytian cotton, reduced in size but only slightly modified in form. (Natural size.)

If each character were at liberty to change independently, the elimination of variations from select stocks would be a well-nigh hopeless undertaking, but the fact that many characters vary together makes it much easier to detect and rogue out the mutations as soon as they appear. For the purposes of Mendelian experiments the existence of varieties differing by only a single character is often assumed, but this has reference to characters with contrasted Mendelian expression, other kinds of differences being disregarded.

The apparent utility of the theory of character units depends largely on the assumption that there are only a few, so that they can all be analyzed by the breeder and separated in pure strains. But in reality the contrasted differences that may be found in a series of hybrids or mutations are extremely numerous. Thus, in cotton there seems to be an apparently endless series of characters that could be formulated on differences of size, shape, position, color, texture, hairiness, and glandular equipment of the various parts of the plants. The largest and most varied series of such differences have been found in progenies of self-fertilized hybrids. According to Mendelian expectations, these should fall into classes characterized by definite distributions of the parental characters, but most of them show characters far outside of the usual range

FIG. 9.—Leaflike bract of Egyptian cotton, with the blade and stipules not completely united. (Natural size.)

of variation of the parental types. Some of the bolls are longer and narrower than in either of the parent types (figs. 13 and 14) and some are shorter or broader (fig. 15). Equally striking variations occur in the involucral bracts. In addition to many other differences of size, shape, texture, color, and marginal teeth, the positions of the bracts are extremely varied. Some plants have the bracts closely appressed to the bolls (fig. 16), while some have them inflated and standing away from the bolls (fig. 17). Another peculiarity is the twisting of the bracts to the side. There is a slight tendency to twisting in the Egyptian cotton, but in some of the hybrids it becomes very striking (fig. 18).

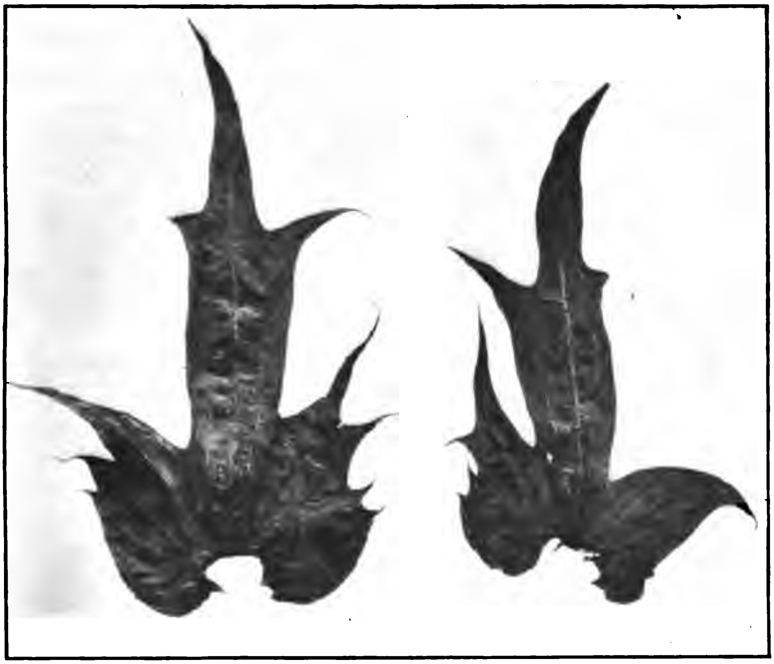

FIG. 10.—Leaflike bracts of Egyptian cotton, with the blade much longer than the stipules. (Natural size.)

Though such hybrids are of no value in themselves, the study of their diversities may aid in the recognition of the less frequent but perhaps equally varied mutations that appear in select stocks. The persistence of the student will determine how many of these variations shall be recognized and described. The descriptive task can be simplified, of course, by confining attention to the extreme forms of variation, but it is no less important to recognize the intermediate members of the series.

In the improvement of the cotton crop, where uniformity of fiber is a primary consideration, the recognition of this principle of simul-

taneous change of expression of many characters is especially important. It enables most of the mutations to be detected early in the season before they have reached the flowering stage. Otherwise they furnish pollen for infecting the seed of their neighbors, with the tendency to degenerate variation. Selection applied at the end of the season is much less effective.[1]

FIG. 11.—Bractlike leaf of Willet Red Leaf variety of Upland cotton. (Natural size.)

Though mutative degenerations can usually be detected by observing the lint and seed characters, it is a much easier method, as well as more effective, to recognize them from the external vegetative characters of the plants. An example of the extent to which mutations often differ from the parent type in lint characters is shown in figure 19, where three seeds from a degenerate mutation are compared with two seeds from an adjacent normal plant in a field of the Lone Star variety at Waco, Tex., in the season of 1911. Though the seed differences are obvious enough when the lint is combed out, this would be unnecessary in actual practice, for the plants that produced the inferior lint could be distinguished from the Lone Star type by simple inspection in the field. For a farmer sufficiently familiar with his variety, the removal of such plants would take no more time than pulling an equal number of weeds and would be much more important for the welfare of the crop.

[1] Cook, O. F. Cotton Selection on the Farm by the Characters of the Stalks, Leaves, and Bolls. Circular 66, Bureau of Plant Industry, U. S. Dept. of Agriculture. 1910.

## DIFFERENCES AND SIMILARITIES OF MUTATIONS.

That mutative variations should differ from the parent variety in many respects rather than in only one or two characters is easier to understand when we remember how the condition of uniformity is attained—by the suppression of the normal individual diversity of the ancestral stock. As the mutations that arise in select strains of cotton show the same general range of diversity as the members of unselected stocks, it does not seem surprising that the mutations should differ from each other and from the parent type in many characters, like the individuals of normally diverse groups.

FIG. 12.—Involucre of Egytian cotton, with outer bract of intermediate form and the others nearly normal. (Natural size.)

In addition to a wide range of diversity among the mutations of the same stock, it is also necessary to recognize cases of closely similar or parallel mutations, like those that have been taken by De Vries and other recent writers as examples of evolutionary change in definite directions. Yet there is no reason to expect that mutations, any more than other variations, should differ indiscriminately or show mere random combinations of characters. Observation of many mutations of cotton and other plants indicates that the general laws of correlation or coherence in the expression of the characters apply among mutations as well as among hybrids and among the normal individual diversities of unselected stocks.

As already noted, the single set of characters shown by each of the many members of a variety corresponds to the equipment of a single individual in a normally diverse group, like the human species. Individual men and women do not differ by single characters or by merely random combinations of characters, but show large series of coordinated differences. The fact of correspondence or interrelation between the different characters of the same individual has been recognized by the great French sculptor Rodin, the competence of whose opinions on the characteristics of the human form will scarcely be questioned. In a recent criticism of the method of constructing ideal human forms by combining characters from different models emphasis is placed on the perception of correlations of characters as an essential of artistic ability and taste. Rodin's views are reported as follows:

> Everything in nature is beautiful for the real artist, for the man of imagination. Nothing is more ridiculous than the effort of an artist to produce something beautiful, something perfect, by combining perfect parts of different models into one. Thus the artist who reproduces the eyes of one model, the hands of another, the feet of a third, the neck of a fourth, produces perhaps a beautiful doll, but it is lifeless and worthless.
>
> There is no such thing as ugliness in nature, in life. Everything is beautiful if seen through the artist's mind. The imperfections become perfect. There is nothing more wonderful than life.[1]

FIG. 13.—Boll of Egyptian-Hindi hybrid, showing extreme variation toward narrow oblong form. (Natural size.)

FIG. 14.—Boll of Egyptian-Hindi hybrid, long, tapering form. (Natural size.)

To bring together characters that do not form natural combinations is unpractical for the breeder as well as inartistic for the sculptor. When incongruous combinations of characters occur in cotton hybrids the plants are usually defective or infertile. Many

[1] "Rodin on the Crisis of Sculpture." Literary Digest, vol. 43, no. 4, 1911, p. 139.

attempts have been made to combine the superior lint of the Egyptian cotton with the superior cultural characters of the Upland cotton, but thus far without success. In the rare cases when plants are actually obtained that combine some of the distinctive features of two types, such as Upland habits of growth and Egyptian flowers or Egyptian vegetative characters and Upland flowers, such plants are likely to produce little or no seed.

FIG. 15.—Short, broad form of boll of Egyptian-Hindi hybrid. (Natural size.)

Though mutations and hybrids can often be separated into distinct classes based on the presence or absence of the more definitely alternative characters, they may have a wide range of individual differences in other respects. The diversity manifested in mutations is like the diversity of hybrids, except that the progenies of mutations usually show a much more stable expression of characters. If desirable combinations of characters are found in mutations, they are much more easily preserved than in hybrids. The fact that most of the mutations are degenerate and worthless should not be allowed to obscure the importance of discovering the rare examples of superior mutations to serve as parents of new varieties.

FIG. 16.—Involucre of Egyptian-Hindi hybrid, with appressed bracts. (Natural size.)

Familiarity with the plants gives the practical breeder something that the statistical expert may not have—an ability to recognize desirable plants by direct perception. A skillful breeder has no more need for a score-card system as a guide in selecting a superior plant than a sculptor has for Bertillon measurements in the choice of models.

Most of the mutations of selected varieties of cotton can be described as small-bolled reversions, for they have smaller bolls than the parent variety. Though small-bolled reversions are likely to agree in many other respects, such as narrower leaves, longer inter-

nodes, and more upright branches, they are still very far from being duplicates. When the progenies of such plants are raised each row seems to represent a different variety. Small bolls were doubtless the rule in the ancestral stock from which the big-boll varieties were separated by selection. The persistent tendency of cotton to vary toward small bolls may be compared with that of breeds of chickens to vary toward red feathers or sheep toward black wool or corn toward red ears.

A general tendency for narrow leaves to be accompanied by smaller fruits has been observed among mutations of the coffee shrub in Central America. Planters recognize that the narrow-leaved plants produce a larger proportion of berries with only one seed of the rounded "peaberry" or caracolillo form, which formerly commanded special prices. As might be expected from the tendency to abortion of seeds, the narrow-leaved variations do not yield as well as the parental type of ordinary "Arabian" coffee, and they have not become favorites in cultivation.

FIG. 17.—Involucre of Egyptian-Hindi hybrid, with inflated bracts. (Natural size.)

Another tendency shared by many otherwise different mutations of cotton is toward a shortening of the internodes of the fruiting branches, resulting in the "cluster" type. The shortening of the internodes probably does not represent an ancestral feature or even a positive character at all, but a loss of the normal specialization of parts of the plant, as already stated in a previous chapter. In Mendelian language, this might be described as the absence of a normal or long-joint character replaced by a short-joint character. But the continued transmission of the normal long joint is shown in cases of reversion that appear in cluster varieties, either as individual variations or as modifications induced by environmental conditions.

The inadequacy of the Mendelian theory that mutative variations are caused by a definite addition or subtraction of character units from transmission has been recognized recently by Gates in the case

of a mutation of Oenothera, that gave very frequent reversions to the parent form. The inference is drawn that such changes of characters must be quantitative rather than qualitative. In other words, they can be considered as arising from differences in the strength of the relations that control the expression of the characters rather than because factors of transmission have been added or removed. Gates summarizes his study of this point in the following statement:

> On account of these reversions in *O.* [*Oenothera*] *rubricalyx*, which happen in the first and in all later generations, its origin can not be attributed to the loss of a "factor" or an inhibitor or other substance from the germ plasm. The change has been a positive one just as it appears to be. The Mendelian presence-absence hypothesis, commonly used to explain the numerous cases of Mendelian color inheritance in plants and animals, will not apply here. The difference between *O. rubricalyx* and *O. rubrinervis* is instead a purely quantitative one, *O. rubricalyx* having originated through a quantitative readjustment of the materials of the germ plasm leading to the formation of the substances which determine anthocyan formation as a product of the plant's metabolism. This hypothesis is rendered necessary by the fact that these quantitative differences in capacity for anthocyan production are strictly inherited, notwithstanding the well-known fact that this character is subject to wide fluctuations owing to environmental conditions. It is probable that many cases of Mendelian color inheritance are to be accounted for as the result of similar heritable quantitative differences, rather than by the hypothesis of the presence or absence of certain factors in the organisms.[1]

FIG. 18.—Involucre of Egyptian-Hindi hybrid, with twisted bracts.

Selection for extreme earliness and fertility favors abnormal reductions of the vegetative parts. Though such abnormalities would not be likely to survive in nature, they may be valuable in domestication. Under favorable conditions cluster varieties of cotton are extremely productive, but they are easily injured by unfavorable conditions. The crop is often lost by the blasting of the buds, or the quality of the fiber may be injured as a result of premature opening of the bolls.

Thus, the selection of plants that make the very highest yields under the most favorable conditions may defeat the object of securing the most valuable stocks for general purposes of production, just as the persistent selection of fowls with the very highest records as egg

[1] Gates, R. R. Studies on the Variability and Heritability of Pigmentation in Oenothera. Zeitschrift für Induktive Abstammungs und Vererbungslehre, vol. 4, pt. 5, 1911. p. 370.

producers has been found to yield a relatively inferior progeny. The loss of the instinct of incubation in many different breeds specially selected for laying qualities may be compared with the general tendency to shortening of internodes in selected varieties of plants. Nonsitting fowls would be as unsuited to survive in nature as "cluster" varieties of plants.

## INTERFERENCE IN EXPRESSION RELATIONS.

The idea that any desired combination of characters can be secured by hybridizing different types of cotton or other plants is in accord

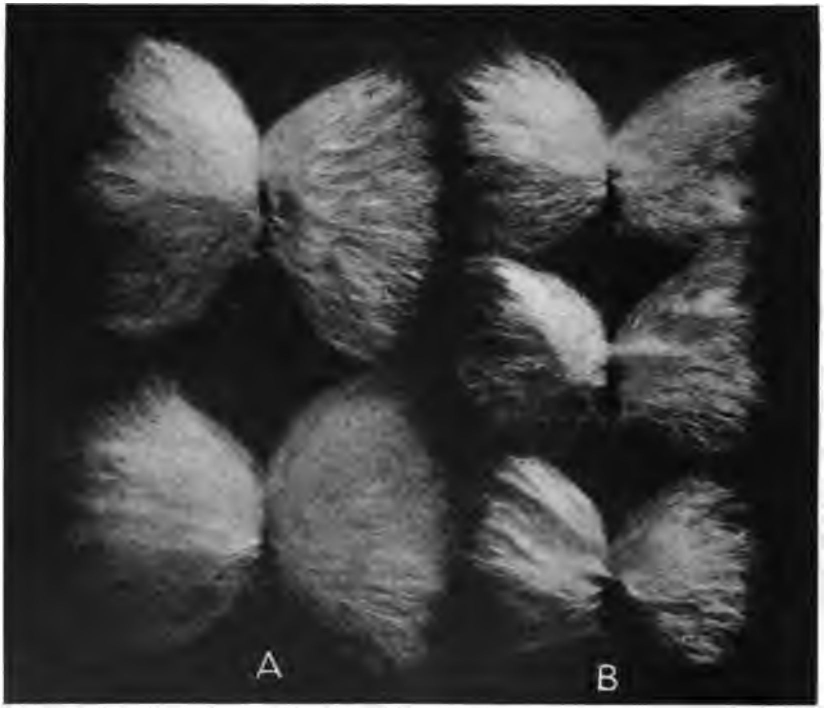


FIG. 19.—Seeds of Lone Star cotton (*A*) and degenerate mutation (*B*), with lint combed out to show comparative length. (Natural size.)

with the theory of characters as independent units capable of separate transmission, but the expression relations are left out of account. In some cases it may be possible to combine two desirable characters in hybrids without interfering with the expression of other characters, but such combinations are often prevented. Strong tendencies to coherence in the expression of a group of characters that have come from the same parent interfere with the substitution of contrasted characters from the other parental group. Thus coherence of characters limits the application of the Mendelian theory of heredity in practical breeding.

That the characters of plants and animals should combine in definite proportions, after the analogy of chemical compounds, is a very attractive idea and is doubtless responsible for the tendency of popular writers to accept assurances based on the Mendelian theory as demonstrated facts. Statements like the following are frequently found in publications on breeding and eugenics:

Pure varieties breeding true can be established permanently by taking into account the Mendelian laws of heredity. Similar results have been accomplished in many other plants and in many animals. A cotton has been produced which combines early growth, by which it escapes the ravages of the boll weevil, with the long fiber of the finest Sea Island varieties. Corn of almost any desired percentage of sugar or starch, within limits, can be produced to order in a few seasons. The hornless character of certain varieties of cattle can be transferred to any chosen breed.[1]

The discrepancy between such an assurance and the actual fact is that the crossing of different types of cotton for purposes of forming Mendelian combinations of contrasted characters does not leave them pure or with the same adjustments of expression of the other characters as before. Though the first generation is often equal or superior to the best members of the parent stocks, later generations are distinctly inferior. The advantages secured by selection are likely to be lost by crossing with a different type. The superiority of selected varieties resides largely in the fact that they show the greatest uniformity in expression of the desired character. When crossing has disturbed this special adjustment of expression relations the superiority of the selected stock is destroyed. Diversity aroused by crossing may serve a useful purpose in furnishing material for a new selection, but this is not the Mendelian idea of forming definite combinations of characters derived from different stocks.

Many of the peculiarities that arise as sudden mutative variations and show Mendelian inheritance are not in the nature of additional characters but represent the absence of normal characters from expression. Hybridization with such variations leads to the subtraction or suppression of characters instead of constituting an addition or positive combination of characters. Mutative variations toward naked, lintless seeds may illustrate this phenomenon in the cotton plant. The lintless character seems to be spreading rapidly in Upland varieties of cotton, especially in the South Atlantic States. The communication of such a negative character by crossing may be much more feasible than the union of two positive characters derived from different stocks, such as the Upland habits of growth and the Sea Island or Egyptian lint.

That mutative suppression of characters is not a rare phenomenon is indicated both in corn and in cotton by the occurrence of albino

[1] Kellicott, W. F. The Social Direction of Human Evolution, 1911, p. 135.

seedlings. As such albino plants never survive to produce pollen or seeds there can be no question that the loss of the green coloring matter occurs quite frequently as an independent variation.[1]

If the superior lint characters of the Sea Island or Egyptian types of cotton could be permanently united with the superior cultural characters of the Upland type of cotton, such as hardiness, earliness, large bolls, and abundant lint, the combination would be valuable. Large numbers of such hybrids have been made, but it has not proved possible to establish their characters by selection. This seems to be prevented by interference of expression relations, as well as by coherence of characters derived from the same parent. Individuals that show definite combinations of the characters of the two types are inferior. Those that show the vegetative characters of the Upland cotton also produce fiber of the short Upland type.[2]

The first generation usually yields better lint than either of the parent varieties, but the later generations are inferior. Perjugate hybrids that have the Upland form not only fail to show long lint like the superior Sea Island or Egyptian ancestor, but usually have very short lint, inferior to that of the original Upland parent of the hybrid stock. The diversities of hybrids, like the mutative variations of selected types, fall into series parallel with the diversities shown in primitive, unselected stocks. In view of the continued transmission of such diversities it is plain that the task of breeding is not to separate the characters in transmission but to understand and control their relations of expression.

An untried possibility of securing more stable combinations of characters derived from different types of cotton has been suggested

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[1] A recent paper by Worsley recognizes such limitations in the application of Mendelism to hybrids between different species of plants, as the following paragraphs will show:

"When I have followed these hybrid progeny by critical analysis into the second and subsequent generations, I have not been able to satisfy myself that reversion to certain specific characters follows the allegations of the Mendelian advocates. In the first place, I have never been able to find in hybrids any characters that were absolutely dominant or recessive, but have only discerned a certain relative or partial inclination toward the specific characters. Nor have I as yet found a single instance of absolute reversion to either specific type; but I have found that, in the subsequent generations, all sorts of intermediate forms crop up equipoised between the hybrid type and either parent. For instance, if the hybrid type inclined towards the male in colour of flower and towards the female in another respect, I find that some individuals in subsequent generations will do just the opposite, as though the law of change indicated a course of variation which would in time fill up every gap between the two extreme forms represented by the species originally crossed * * *. We constantly find that certain pairs of characters can not be dissociated from each other, but continually occur together in individuals. This association of certain characteristics (so long as it obtains) appears to rule out the possibility of the occurrence of certain conceptually possible intermediate forms. The Antirrhinums give us one instance of this, for among the dwarf self-colored forms every rogue as to height is also a colour rogue, whereas those that are typical in stature will probably not produce 1 per cent of colour rogues." (See Worsley, A., "Variation as Limited by the Association of Characters." Journal Royal Horticultural Society, vol. 36, pt. 3, May, 1911, pp. 596–597.)

[2] Cook, O. F. Suppressed and Intensified Characters in Cotton Hybrids. Bulletin 147, Bureau of Plant Industry, U. S. Dept. of Agriculture, 1909, p. 16.

by a study of diversity. In stocks of Egyptian cotton that have been exposed in previous years to natural crossing some of the lines of descent undoubtedly represent dilute hybrids with Upland or Hindi cotton, in spite of the roguing out of all individuals that showed any definite indication of hybridization in previous generations. Some of the mutative reversions that have appeared in stocks of Egyptian cotton have shown more stable combinations of Uplandlike habits of growth and Egyptianlike lint than any of the hybrids that have been produced artificially.

The suggestion is, therefore, that hybridization may serve as a practical means of inducing mutative variations in desired directions in order to secure more stable combinations of characters than are afforded by the more direct methods of hybridization hitherto employed. Mutative reversions often occur as echoes of previous crossing, even after many generations, a fact very familiar to breeders, but such variations do not appear to have been considered as of possible value from the breeding standpoint. That hybridization is responsible for mutations has often been suggested, even in connection with the original examples of the mutation theory—the forms of *Oenothera lamarckiana* described as mutative new species by De Vries. The recent investigations of Davis are pointing more definitely in this direction.[1]

While none of the mutative reversions toward Upland characters in Egyptian stocks have shown such uniform progenies as some of the mutations that have been found in Upland varieties, no complete uniformity could be expected in view of the fact that the parent individuals have produced their seed under conditions of open pollination. That any considerable proportion of the progeny should express the parental characters and be alike among themselves shows a much more stable condition of heredity than has been found to exist in the progenies of any of the individuals that have been selected from second and third generations of hybrid stocks.

This possibility of inducing mutative variations with desirable combinations of characters also seems to be indicated by facts observed in the Durango cotton. Several years ago many hybrids had been made between the Durango cotton and the Triumph variety of American Upland, in order to combine the larger bolls of the Triumph variety with the longer lint of the Durango type, but this work had been discontinued because no uniform progenies of desirable plants were secured. Many large-bolled, Triumphlike plants had also been selected in the Durango stock, but all these were rejected as probably representing accidental hybrids with Triumph,

[1] Davis, B. M. Genetical Studies on Oenothera. American Naturalist, vol. 45, April, 1911, p. 193.

the variety chiefly grown in the vicinity of the earlier experiments. All of these selections behaved like hybrids in their failure to yield uniform progenies.

Nevertheless, occasional large-bolled Triumphlike plants have continued to appear in the Durango cotton and three progenies raised from such plants at Del Rio, Tex., in 1911, were notably uniform, as though the desired combination of characters had finally been secured by mutative variation from the Durango type. If the uniformity of expression continues, superior strains can be developed from these variations. They have the more upright habit and long lint of the Durango type, together with the larger bolls and more abundant lint of the Texas big-boll type. Two of the large-bolled selections showed another big-boll character, an increased proportion of 5-locked bolls. The percentages of 5-locked bolls in these two cases were 42 and 50, while two adjacent rows representing progenies of typical Durango plants showed only 27 and 29 per cent of 5-locked bolls.

The lint percentage was somewhat higher in the large-bolled selections than in the typical Durango type. Yet there seemed to be no constant relation between the lint percentage and the number of locks in the bolls. Another selection with large Triumphlike bolls gave the highest percentage of lint—36 per cent—though in this case only 21 per cent of the bolls were found to have five locks. This indicates a freedom of combination of the Triumph characters in these induced mutations, much as would be expected in Mendelian hybrids. If such mutations prove valuable, they will afford another reason why breeders should not disregard everything except pure lines.

That the percentages of 5-locked bolls represent significant differences among the Durango selections will be seen from the totals shown in Table IV:

TABLE IV.—*Census of bolls in 5 progeny rows of Durango cotton at Del Rio, Tex.*

| Progeny No. | 3-locked bolls. | 4-locked bolls. | 5-locked bolls. | Percentage of 5-locked bolls. | Percentage of lint. |
|---|---|---|---|---|---|
| 8 | 0 | 523 | 529 | 50 | 34 |
| 23 | 5 | 742 | 274 | 27 | 33 |
| 25 | 1 | 583 | 421 | 42 | 36 |
| 29 | 0 | 711 | 289 | 29 | ........... |
| 30 | 2 | 791 | 215 | 21 | 36 |

## EXPRESSION RELATIONS AFFECTED BY EXTERNAL CONDITIONS.

Expression is influenced by external conditions as well as by internal relations with other characters. That changes of external conditions often result in changes of characters has long been known,

and such facts have often been supposed to demonstrate the possibility of improving plants and animals by direct environmental influences. The question whether nature or nurture has the more important influence in development has been widely debated, often to the neglect of the fact that both are essential to full expression of the normal characteristics of a stock. Unless the substratum of transmission is present and accompanied by the necessary potencies of expression the most favorable conditions are powerless to produce a desired character. On the other hand, the most desirable tendencies may prove ineffective in the presence of too unfavorable conditions.

Many differences in degree of development of characters can be looked upon as standing in a direct relation to favorable or unfavorable external conditions. This interpretation of environmental changes does not always suffice. It often becomes evident that some of the changes must be induced indirectly by environmental modifications of internal relations of expression. Cotton plants of the same strain do not merely grow larger in some places than in others, but change their habits of growth, the form of their branches and leaves, the number of carpels in the bolls, and even the color of the fuzz on the seeds.

The Egyptian cotton has different forms of foliage for sun and shade conditions. At Bard, Cal., in October, 1911, it was noticed that leaves of the main stalk and vegetative branches growing in the sun had at least five distinct lobes and those of the fruiting branches at least three lobes. Under shade conditions the leaves of the vegetative branches had three very broad lobes, while those of the fruiting branches were often simple or without lobes. The last was true especially of the lower leaves produced from vegetative shoots in the latter part of the season when there was more shade.

Changes of branching habits in response to different conditions make it evident that there is no complete determination in advance as to whether vegetative or fruiting branches shall be produced. There is a normal sequence in the production of the two kinds of branches, only the vegetative type being produced from the lower nodes of the stalk, but the change from the vegetative to the fruiting type is subject to adaptive accommodation during the development of the plant.

If environmental changes of characters were merely physiological or quantitative the theory of direct adaptation might be sufficient, but such changes are not confined to characters of environmental utility. Many changes of characters induced by environment are disadvantageous, as when cotton plants show excessive development of vegetative branches and fail to ripen seed.

Recognition of the fact that the plants often change their characters without change of external conditions makes it easier to under-

stand how environmental changes may be brought about. Differences that arise in the same stock of plants under different conditions are subject to the same general interpretation as differences that arise under the same conditions, in that both kinds of differences may be supposed to represent changes of expression relations. The characters that are shown in one place belong to the plants as truly as those that are shown in another place. There are environmental alternatives of expression as well as sexual or Mendelian alternatives. The same nodes on the stalk of a cotton plant will produce fruiting branches under some conditions and vegetative branches under other conditions. In this case, indeed, the same character seems to have both Mendelian and environmental relations of expression, for Leake has announced on the basis of experiments with Indian cottons that the habits of branching are inherited in Mendelian fashion. Special attention has been called to this phase of the subject in a recent address of Prof. Bateson.[1]

The varieties that Leake describes as "sympodial" differ from those called "monopodial" merely in producing fruiting branches lower down on the main stalk. As already indicated, these differences are strictly quantitative and physiological, and are readily affected by external conditions, even to the extent that a plant that would be called strictly "sympodial" in one place will become altogether "monopodial" in another, in the sense that all the fruiting branches are transformed into vegetative branches.

Under current theories of Mendelism the failure of one of the contrasted characters to appear is ascribed to a failure of transmission. On this basis it would not be possible for the same varieties of cotton to show the "sympodial" habit in one place and the "monopodial" habit in another. But the facts stated by Leake may be considered as evidence against the application of the Mendelian theory that heredity is a process of alternative transmission. With expression

[1] "A simple and interesting example is furnished by the work which Mr. H. M. Leake is carrying out in the case of cotton in India. The cottons of fine quality grown in India are monopodial in habit, and are consequently late in flowering. In the United Provinces a comparatively early flowering form is required, as otherwise there is not time for the fruits to ripen. The early varieties are sympodial in habit, and the primary apex does not become a flower. Hitherto no sympodial form with cotton of high quality has existed, but Mr. Leake has now made the combination needed, and has fixed a variety with high-class cotton and the sympodial habit, which is suitable for cultivation in the United Provinces. Until genetic physiology was developed by Mendelian analysis, it is safe to say that a practical achievement of this kind could not have been made with rapidity or certainty. The research was planned on broad lines. In the course of it much light was obtained on the genetics of cotton, and features of interest were discovered which considerably advance our knowledge of heredity in several important respects. This work forms an admirable illustration of that simultaneous progress both towards the solution of a complex physiological problem and also towards the successful attainment of an economic object which should be the constant aim of agricultural research." (See Bateson, W., "Genetics," Popular Science Monthly, vol. 79, no. 4, October, 1911, p. 319; see also Leake, H. M., "Studies in Indian Cotton," Journal of Genetics, vol. 1, September, 1911, p. 205.)

recognized as distinct from transmission there is no reason to deny the possibility that a character expressed in Mendelian fashion among hybrids may also be suppressed or intensified by external conditions. It becomes possible to understand that alternative characters of branches or other organs may remain susceptible to environmental influences as well as to internal relations that govern expression. The influence of external conditions upon heredity has been recognized as one of the most important phases of the subject and one of the most difficult of investigation. An easier approach to such problems is opened by observing the distinction between transmission and expression. The power of the environment to influence the expression of characters can be recognized without assuming that new characters are acquired from external conditions.

In addition to the cases where the expression of characters is definitely limited or modified by the external environment there are instances where expression seems to be only slightly modified or modulated to correspond with the more pronounced environmental changes. If external conditions induce the formation of more rounded bolls a shortening of the lint takes place, just as when there has been a definite change of character, as in round-bolled mutations or reversions. Such differences are sometimes quite clearly marked in parts of the same individual plant. Where cotton plants have been checked by drought and afterwards revived, the "top growth" of previously normal plants usually has smaller and more rounded bolls and shorter lint, similar to those of many small-bolled reversions.

Whether such changes are inherited to any extent through the seed has not been demonstrated by any adequate experiments. There is a general belief that the seed of the last picking is not so good for planting as the seed of the first or second picking. In some cases the first picking is also inferior, owing to the fact that many of the very early bolls are poorly developed and are opened prematurely.

The lint also responds in various ways to adverse conditions of growth. In addition to the general weakness of the lint in prematurely opened bolls, the fiber may also be shortened if the adverse conditions affect the boll in the early stages of growth. Another effect of adverse conditions is to render the lint sparse, as well as short. Sometimes these effects are shown unequally on the different parts of the same seed. The upper end of the seed may have lint of normal length and abundance while the lower end has only sparse or short fibers, aggravating the so-called "butterfly" tendency so frequent in our long-staple Upland varieties.

## GENERAL CONCLUSIONS REGARDING THE NATURE OF HEREDITY.

Correct interpretations of the facts of heredity are essential to safe application in practical breeding. The investigator should be able to think correctly about the facts that he observes and to appreciate their relations with other facts. Progress in interpretation lends additional value to the results of investigation, like other improvements in methods of conducting experiments and recording observations.

Heredity includes two distinct processes—transmission and expression. If heredity is to be considered from a mechanical standpoint, two kinds of mechanisms should be recognized, a mechanism of expression as well as a mechanism of transmission.

Transmission is independent of expression and probably includes a complete series of ancestral characters. Characters can be transmitted through many generations in a latent condition, without being brought into expression. The study of many problems of heredity and breeding can be facilitated by more definite recognition of the distinction between transmission and expression.

The differences everywhere found among the members of species of plants and animals are the facts that give practical importance to the study of heredity. Such differences should be considered as variations in the expression of characters, not as variations of transmission. Changes of characters that arise in response to changes of external conditions or to different methods of breeding also represent changes in the expression of the characters rather than changes in transmission.

While it would be a matter of much scientific interest to discover the method of transmission, the practical object of the study of heredity is to learn how to control the expression of characters. Expression is influenced by the mutual relations among the characters as well as by external conditions and methods of breeding. The investigation of expression relations should not be limited to empirical discovery of correlations by measurements of sizes, weights, or colors, but should include a biological recognition of expression relations in unimproved stocks and in hybrids.

The idea that variations represent changes in the expression of characters rather than changes in transmission is in accord with the general manifestation of diversity among the members of natural species and the general tendency of domesticated varieties to revert to the ancestral condition of diversity.

Though the recognition of individual diversity and free interbreeding as normal conditions of heredity conflicts with current theories of descent in pure uniform lines, it is necessary to an appreciation

of the physiological factors of heredity, those that sustain organic vigor and fertility.

The union of the lines of descent of a normally diverse interbreeding species into a network provides for the transmission of all the ancestral characters through all the lines of descent. Undesirable characters are suppressed by selection, but not eliminated from transmission, as shown by the fact of reversion. The function of selective breeding is to secure more regular expression of a desired set of characters. Continued selection is required to maintain the uniformity of superior varieties, because of the persistent tendency of the suppressed characters to return to expression.

The diversity that is aroused by placing a variety under new or unfavorable conditions and the diversity induced by hybridization can both be looked upon as due to the return of latent characters to expression. It is not necessary to assume that new characters are added to the transmitted stock, either by new conditions or by hybridization.

Selection regulates the expression of characters, but is not known to have any influence over the transmission of characters or the addition of new characters to the content of transmission. The evolutionary development of new characters should not be confused with changes in the expression of old characters. Mutative changes of expression are not to be considered as new characters or as examples of the evolutionary progress of natural species.

The normal results of the workings of heredity seen in natural species are not separate lines of uniform individuals but highly varied fabrics or networks of interbreeding lines of descent. Uniform expression of characters, as in line-bred groups, represents an artificial condition of heredity and is accompanied or followed by a decline of vigor and fertility.

Increased vigor and fertility secured by crossing selected strains is to be considered as a result of returning toward a more normal condition of reproduction, like that of natural, freely interbreeding species. It should not be identified with the abnormal vegetative or somatic vigor sometimes shown by sterile hybrids between different species.

Mendelian combinations of characters of different types of cotton are prevented by the fact of coherence. Instead of a Mendelian segregation and recombination, there is a general tendency for characters derived from the same parental type to remain together in expression in the hybrids.

The transfer of a desired character from one variety to another by Mendelian combination of characters may be possible in cases where the desired character is negative or suppressed, but Mendelian com-

binations of positive characters are much less frequent, if they occur at all.

The evolutionary development of new organs and functions involves the addition of new characters to the content of transmission, but such new characters are to be distinguished from variations that represent changes in the expression of characters already present in transmission.

## SUMMARY OF APPLICATIONS TO METHODS OF BREEDING.

The practical study of heredity should begin with a recognition of the underlying facts of normal individual diversity and free interbreeding among diverse individuals, as shown in wild species and unimproved domesticated stocks. Uniform expression of characters is not a natural condition of heredity in a cross-fertilized plant like cotton, but has to be secured and maintained by selection.

The effect of propagation from a single parent or in very narrow lines of descent is to establish or stabilitate expression, so that a single set of characters is shown in a large number of individual organisms. Normal diversity is suppressed, but the suppressed characters continue to be transmitted in latent form and return to expression in mutative reversions.

In view of the continued transmission of latent or suppressed characters and the frequent return of such characters to expression, it is not to be expected that selection can be completed once for all by the separation of "pure lines," as inferred from the assumption of normally uniform heredity. In a seed-propagated crop plant like cotton continued selection must be maintained if the uniformity of superior varieties is to be preserved. The value of such selection does not depend on the possibility of securing further improvements, but on avoiding degeneration by loss of uniformity.

The idea that there is a natural uniformity or stability of expression of characters applies to natural species only in cases where special methods of reproduction, such as vegetative propagation, parthenogenesis, and self-fertilization, furnish the same conditions of restricted descent as in domesticated species. Vegetative propagation is the most effective method of securing an unaltered expression of the characters of a selected individual, but even in vegetatively propagated varieties changes of expression sometimes occur.

The establishment of uniform expression of characters involves a departure from the normal condition of free intercrossing between different individuals and lines of descent and an ultimate decline in vigor and fertility. Uniform groups become inferior in these respects to hybrids or to select individuals of unimproved stocks.

The loss of vigor and fertility as a result of descent in narrow lines is to be recognized as a general physiological relation or "law of nature." The result appears much more promptly in some groups than in others, but an ultimate deterioration is to be expected in all. While this fact does not diminish the importance of breeding superior strains of domestic animals and plants, it has important bearings on the choice of methods of breeding, testing, and utilizing such strains. Moreover, it shows the need of providing in advance for the continued development of superior new strains to replace those that have begun to decline in vigor and fertility.

The primitive, wild, or unselected stocks from which our highly selected varieties have been derived ought not to be disregarded or allowed to become extinct on the supposition that they have no further agricultural value. Such stocks may be required at any time in the future as sources of new strains.

It is also important for purposes of practical breeding to take into account the facts of heredity in natural species, in order to learn the best methods of maintaining the uniformity of select strains and of preserving vigor and fertility. Some characters have mutual relations of expression and produce more congruous and more stable combinations. Other characters show distinct incompatibility of expression, resulting in weak or infertile plants.

Comparison of variations in select strains with variations in unselected stocks and wild species of cotton shows that parallel series of variations run through the whole group. Correlations of variations in selected stocks and coherence of parental characters in hybrids seem to follow the same general lines in all the species and varieties of cotton that have been studied from this point of view.

Many of the abnormalities that arise in hybrids and in mutative variations of select strains represent a failure of normal specialization among the parts of the plant, as in the shortened fruiting branches and leaflike involucral bracts of the so-called "cluster" cottons. Such abnormalities are usually accompanied by a tendency to sterility or abortion of buds and bolls and on this account are to be avoided in the breeding of new varieties.

Characters of no practical value in themselves may be worthy of careful study as indications of changes of expression of other characters, as in the case of the paler petal spots that are regularly accompanied by small bolls in the Jannovitch variety of Egyptian cotton. The recognition of degenerative mutations and the preservation of uniformity in superior stocks is rendered much more feasible by the fact that the definite changes in the expression of characters are usually simultaneous. A definite variation in one character is usually accompanied by variations in other characters. Plants that would produce inferior lint can be distinguished by vegetative differences

before the flowering stage is reached, and their prompt removal prevents the distribution of the pollen of inferior plants by insects.

Both in hybrids and in individual variations of selected stocks of cotton there are relations of expression between boll characters and lint characters, so that the nature of the lint can be judged by inspection of unopened bolls and undesirable variations rejected in advance of the harvesting of the crop.

The two color characters of cotton flowers, the yellow of the petals and the purple of the spots, have very different expression relations. In hybrids between Egyptian and Upland varieties the expression of the lemon-yellow color of the Egyptian petals accompanies other Egyptian characters and is only very rarely combined with distinctive Upland characters. The purple base of the Egyptian petals combines much more readily with Upland characters.

Knowledge of expression relations is also required for effective utilization of hybrids of cotton, corn, and other annual crops for purposes of production. The superior vigor and fertility of conjugate hybrids when compared with select parental varieties grown under the same conditions justifies the use of such hybrids for agricultural purposes of production whenever practicable. The increased vigor and hardiness of hybrids is to be considered as a factor of adaptation when it makes possible the production of good crops under conditions too unfavorable to be resisted by the pure-bred parent varieties.

Variations toward Upland or Hindi characters arising in dilute hybrid stocks of Egyptian cotton have been found to yield progenies with more stable expression of characters than direct hybrids between Egyptian and Upland cotton. Such facts suggest the possibility of developing a new method of breeding by dilute hybridization. By the use of a small proportion of foreign blood as a means of inducing mutative variations in otherwise uniform stocks it may be possible to secure desired combinations of characters in more stable form than they can be obtained by direct hybridization.

The deterioration of the later generations of hybrids may be considered as a return to the expression of the characters of more remote and inferior ancestors; in other words, a loss of the potency of expression of desirable characters that was established by the selection of the parental stocks. Thus, the same general result is reached by hybridization as by neglect of selection. There is a return toward the ancestral condition of variable expression of characters.

# PLATES.



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## DESCRIPTION OF PLATES.

PLATE I. Fig. 1.—Kekchi cotton at Bard, Cal., 1911: *A*, Unacclimatized; *B*, acclimatized. The large unacclimatized plant produced only the single boll visible near the base of the main stalk, while the acclimatized plant was heavily loaded with open and unopened bolls. Fig. 2.—Kekchi cotton at Glendale, Cal., 1911. Unacclimatized row at left, acclimatized row at right. In the cooler climate near the coast there were no pronounced differences in the vegetative development of the two rows. The acclimatized stock had somewhat larger bolls and better lint.

PLATE II. Normal and abnormal involucres of perjugate (second generation) hybrids between Egyptian and Upland cotton, showing the larger bracts and longer pedicels of sterile involucres: *A*, Hybrid between Mit Afifi Egyptian cotton and Triumph Upland cotton; *B*, hybrid between Mit Afifi Egyptian cotton and Willet Red Leaf Upland cotton.

PLATE III. Bolls of Egyptian-Upland hybrid: *A*, From parent plant; *B*, from plant grown from cutting. The bolls produced from the cutting were as large as any that have been produced by seedling plants.

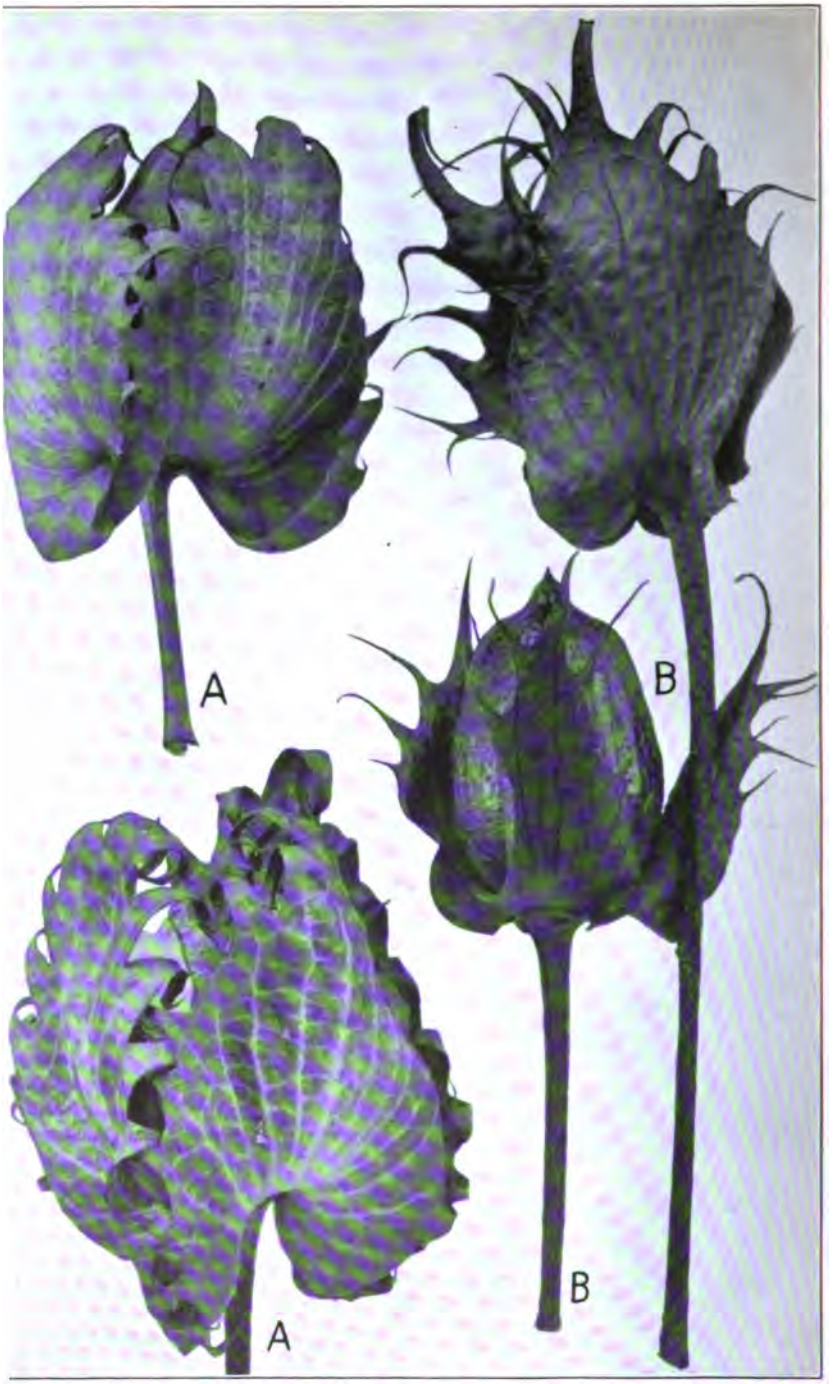
PLATE IV. Abnormal involucral bracts of Egyptian cotton, Yuma variety, showing different degrees of specialization and union of the elements that correspond to the blade and stipules of unspecialized leaves. In some cases the stipules are only slightly modified and only slightly attached to the blade. In other cases the specialization is nearly complete, with the parts separated only by a seam or suture instead of being completely fused as in normal bracts.

PLATE V. Involucral bracts of Upland "cluster" cotton, "Jackson Limbless": *A*, Normally specialized bracts; *B*, abnormal, intermediate bracts. Deeply divided involucres are often met with in cluster varieties.

PLATE VI. Egyptian cotton leaves from three successive internodes, *A*, *B*, and *C*, showing variations of blade and stipules. *A* and *C* represent leaves of the normal 3-lobed form, with small stipules; *B*, the intervening simple leaf with one of the stipules greatly enlarged, representing a partial expression of the characters of the involucral bracts. But after producing an abnormal internode the fruiting branch was able to produce other normal internodes.

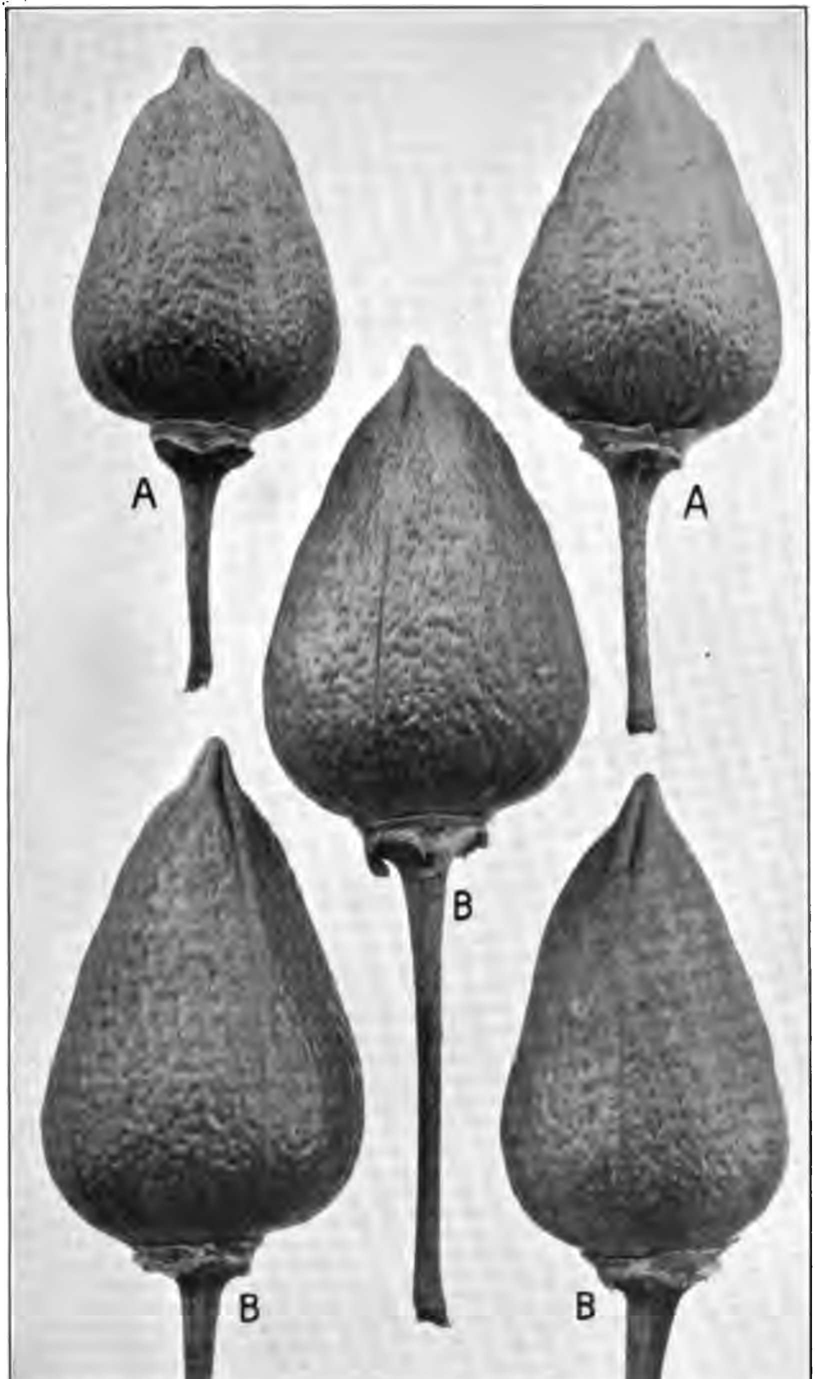

FIG. 1.—PLANTS OF KEKCHI COTTON AT BARD, CAL.: *A*, UNACCLIMATIZED; *B*, ACCLIMATIZED.


FIG. 2.—TWO ROWS OF KEKCHI COTTON AT GLENDALE, CAL.: *A*, UNACCLIMATIZED; *B*, ACCLIMATIZED.



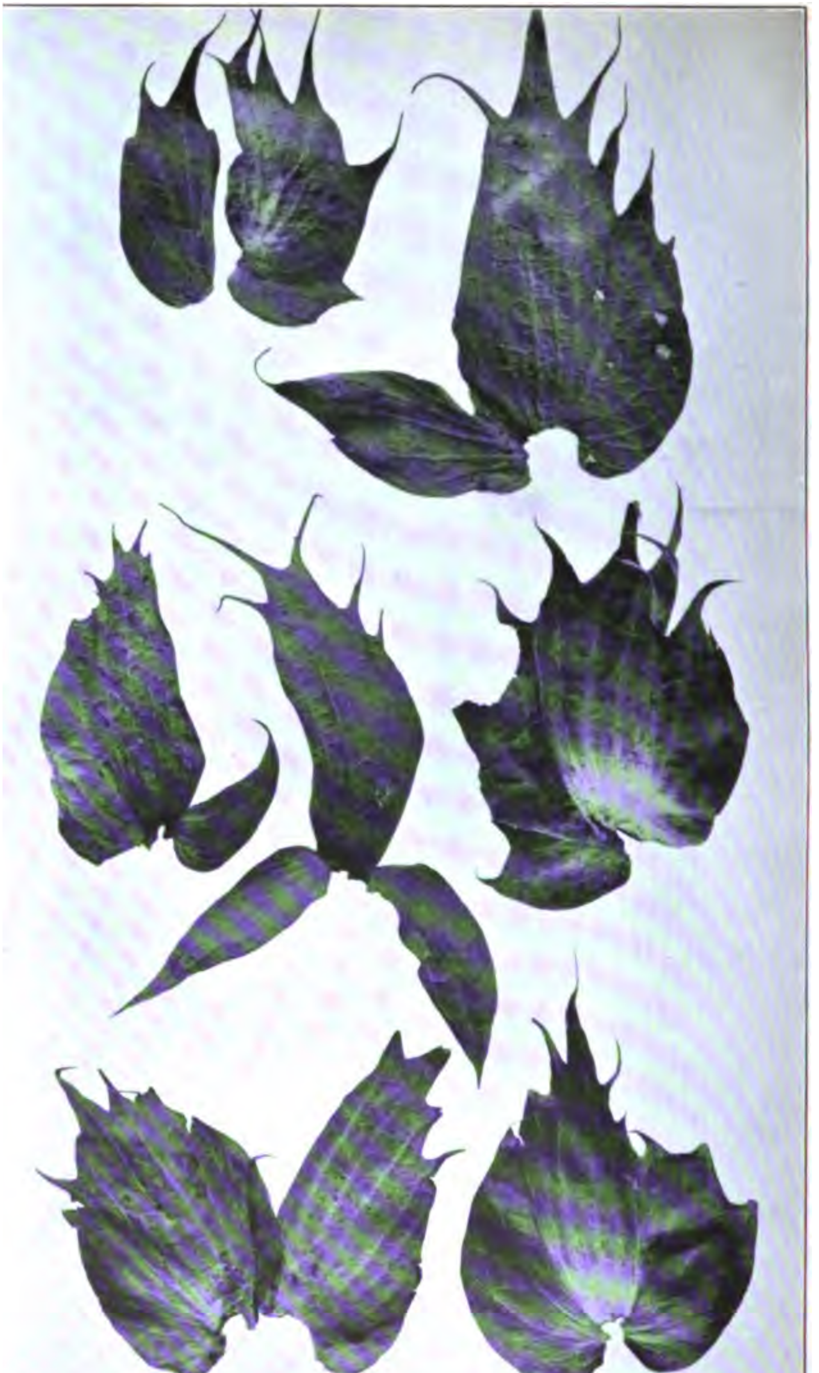

INVOLUCRES FROM TWO PLANTS OF EGYPTIAN-UPLAND HYBRIDS: *A*, NORMAL; *B*, ABNORMAL.

(Natural size.)




BOLLS OF EGYPTIAN-UPLAND HYBRIDS: *A*, FROM PARENT PLANT; *B*, FROM PLANT GROWN FROM CUTTINGS.

(Natural size.)

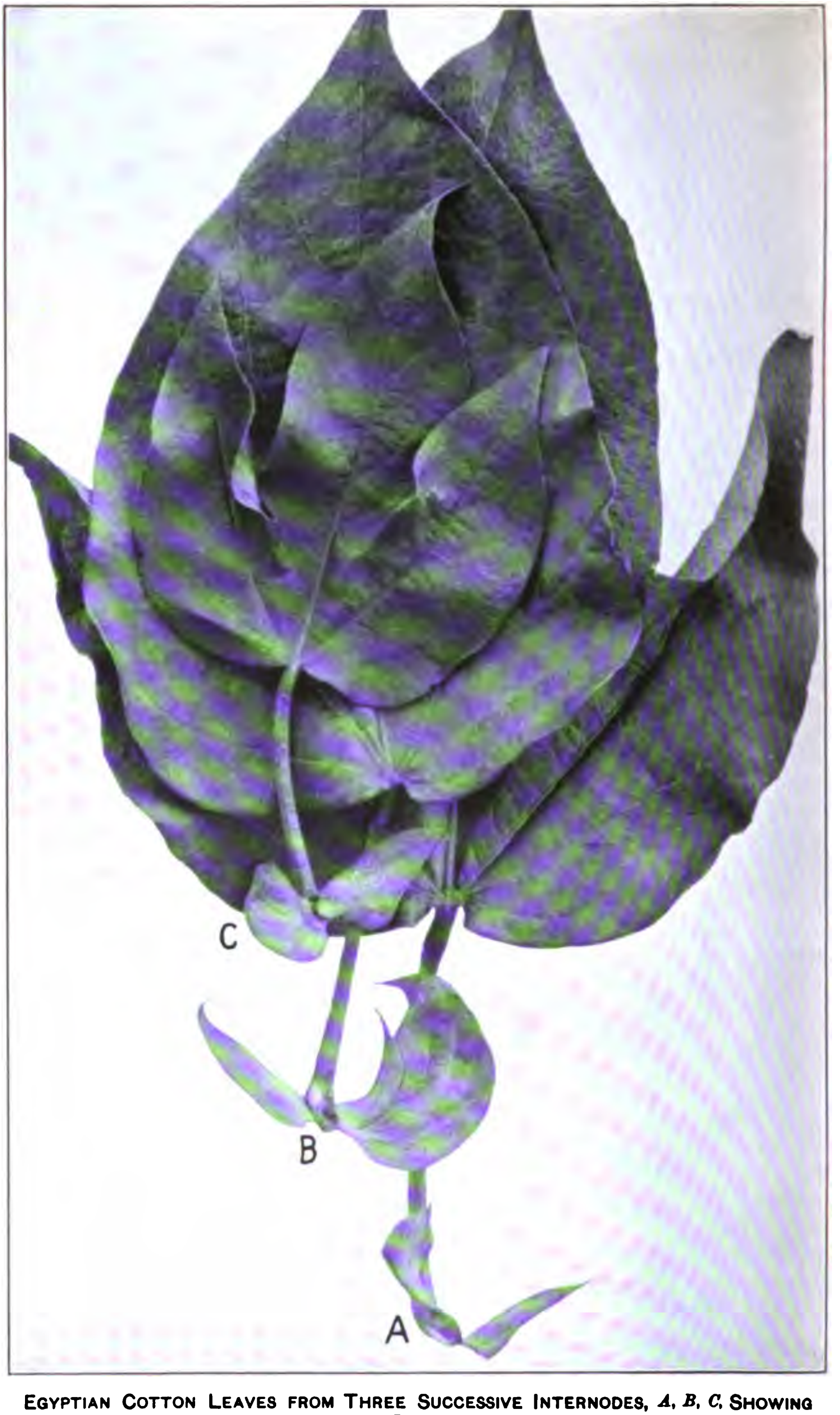


ABNORMAL BRACTS OF EGYPTIAN COTTON, WITH STIPULAR ELEMENTS NOT COMPLETELY UNITED.

(Natural size.)


INVOLUCRAL BRACTS OF "CLUSTER" COTTON, "JACKSON LIMBLESS": *A*, NORMALLY SPECIALIZED BRACTS; *B*, ABNORMAL, INTERMEDIATE BRACTS.

(Natural size.)




EGYPTIAN COTTON LEAVES FROM THREE SUCCESSIVE INTERNODES, *A*, *B*, *C*, SHOWING VARIATIONS OF BLADE AND STIPULES.

(Natural size.)

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U. S. DEPARTMENT OF AGRICULTURE.

BUREAU OF PLANT INDUSTRY—BULLETIN NO. 257.

B. T. GALLOWAY, *Chief of Bureau.*

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# THE WEED FACTOR IN THE CULTIVATION OF CORN.

BY

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AND

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# LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Plant Industry,
Office of the Chief,
*Washington, D. C., May 18, 1912.*

Sir: I have the honor to transmit herewith a manuscript entitled "The Weed Factor in the Cultivation of Corn," prepared by J. S. Cates, Assistant Agriculturist, and H. R. Cox, Agriculturist, in the Office of Farm Management, and to recommend its publication as Bulletin No. 257 of the Bureau of Plant Industry.

This manuscript reports the results of 125 experiments conducted for the purpose of determining the relation of weeds to the tillage requirements of the corn crop. These results show comparative yields of corn on one set of plats under the most approved methods of cultivation and on another set with no cultivation whatever, the weeds being eliminated, however, by surface scraping with a hoe. This work seems to involve a fundamental point and sheds considerable light on the subject of tillage.

Respectfully,

B. T. Galloway,
*Chief of Bureau.*

Hon. James Wilson,
*Secretary of Agriculture.*

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# THE WEED FACTOR IN THE CULTIVATION OF CORN.

## INTRODUCTION.

Corn is one of the most important crops in the United States. Cultivation is one of the most expensive operations in the production of corn. It is also the operation which, of all phases of corn growing, has probably received the least study or about which we have the least fundamental knowledge.

The soil-mulch theory of tillage has been a fundamental one in American agriculture. It was long ago found that by means of a mulch crops could be grown in alternate years on land receiving such scant rainfall as to make it impossible to grow any satisfactory crop by other methods. In studying the effect of the mulch it has come to be generally recognized that in most soils moisture can be saved by maintaining the top portion of the soil in a finely divided condition. It has also been found that frequent stirring of the soil promotes rapid nitrification. It would seem to follow naturally that a system of cultivation which promotes nitrification and conserves moisture would be an extremely valuable system to apply to a tilled crop. In practice it has been found that in most cases frequent shallow cultivation gives better yields than other methods of corn tillage. Upon this experience tillage philosophy has been developed and tillage practice based.

In this publication data are presented with reference to the weed factor in corn cultivation. A direct comparison has been made between what is considered the ideal method of cultivation for corn in each section in which the experiment was conducted and simply removing the weeds without stirring the soil or producing a mulch. The measure of the relative merits of the two systems has been, not in the preservation of soil moisture, or the effect on nitrification, or the making available of plant nutrients, but the relative yields of corn produced.

Experiments aggregating 125 scattered over 28 States are here recorded. Of this number 12 have previously been recorded in experiment-station literature. A study of the results obtained in these 12 early experiments made it seem desirable to take up in a

broad national way the subject of the relation of weeds to the cultivation of corn. Consequently, in the year 1906 a circular letter was sent to the different agricultural experiment stations in the United States giving a general summary of the results already secured and inviting them to cooperate in carrying on simultaneously, through a wide range of soils and climatic conditions, an experiment as outlined to test the relative merits of the mere removal of weeds as compared with supposedly ideal cultivation. A list of graduates of agricultural colleges who are engaged in farming in the various States, together with a number of reliable farmers not coming under that classification, was compiled, and these men were also invited to cooperate with the Department of Agriculture in carrying on the test. The results of these experiments are given in the following pages.

In the tables presented in this bulletin the yields of the uncultivated but weeded plats are expressed in percentages of the cultivated plats, both for fodder and for grain. In the precipitation columns of the tables are given, first, the actual rainfall for a 12-month period, including the last three months of the previous year and the first nine months of the current year, then the mean annual rainfall, and finally the percentage of the actual rainfall expressed in terms of the mean. The records of the weather station nearest to each point where the experiments were conducted or of the station where conditions are most comparable were taken. The columns containing the remarks on soils and climatic conditions give the observations of each of the cooperators covering these points. The headings of the other columns of the tables are self-explanatory.

## METHOD OF CONDUCTING THE EXPERIMENTS.

The early tests of five agricultural experiment stations covering the relation of weeds to the tillage requirements of corn were all conducted as a part of a series of experiments on the depth of cultivation. All of them had plats of deep and shallow cultivation, and some had medium-tilled, "standard"-tilled, and mulched plats. The non-tilled plats were referred to as having been "hoed" or "scraped" in all the experiments except those in Utah, where they were "scarified" with a scuffle hoe.

In the work conducted by the Department of Agriculture, beginning in 1906, an outline was furnished each cooperator describing in detail how the test should be made. The salient points in the outline were as follows: A piece of land of very even productivity was to be selected; preparation for planting was to be made by thorough breaking and harrowing and the planting was to be done by drilling on level land—that is, without ridges.

The size of the plats was left to the cooperator. In the work from 1906 to 1910 the plats consisted for the most part of five rows each, making with the one intermediate row which was discarded at harvest, 11 rows in the experiment. In the work of 1911 most of the experiments were conducted on four plats of five rows each, with three intermediate rows, one between every two plats, which were discarded at harvest. The length of the plats varied with the convenience of each man, the average length being about 250 feet.

After planting, one plat or series of plats was to receive absolutely no cultivation, the weeds and grass being removed at frequent intervals

FIG. 1.—Typical appearance of the soil on a cultivated plat of corn.

by means of a sharp hoe. This hoe was to be used with a horizontal stroke to cut off the vegetation at the soil surface, and particular care was to be paid not to stir the soil any more than was absolutely necessary. The other plat or series of plats was to receive the ordinary cultivation and in addition to have the weeds and grass removed by chopping so as to eliminate the weed factor. Figure 1 shows the typical appearance of the soil on a cultivated plat and figure 2 on an uncultivated plat when the plants had reached the tasseling stage. These illustrations show the tests at the Arlington Experimental Farm on a stiff clay soil where the surface of the uncultivated plats was nearly as dry and hard as a floor.

The cooperators entered into the work with enthusiasm, and as a rule the tests were well conducted. Many experimenters were visited each year by a representative of the Bureau of Plant Industry, who advised with them on the subject. At the completion of the tests detailed statements of the various phases of the experiment were reported on special blanks furnished by the Department. Some of the reports were incomplete or indicated that the work had not

FIG. 2.—Typical appearance of the soil on an uncultivated plat of corn.

been properly carried out. All such were discarded in the final compilations.

## EARLY EXPERIMENTS IN CORN CULTIVATION.

Probably the first agricultural experiment station, at least in this country, to take note of the weed factor in cultivation was the New York State station, at Geneva. The results are presented in the annual report of that station for 1886. Sturtevant in discussing these results says:

If this experiment has a meaning, it is that cultivation is not beneficial to the corn plant except so far as removing the weeds is concerned. Strangely enough, we have during the existence of the station been unable to obtain decisive evidence in favor of cultivation.

The next station to take up this study was Illinois. Under the direction of Morrow and Hunt the work was begun in 1888 and continued until 1893; it was taken up again in 1896, thus covering seven years.

In 1889 and 1890 the Missouri Agricultural Experiment Station made investigations on the depth of cultivation and included plats that were weeded but not cultivated. These experiments included the effect of the treatments on soil moisture for the year 1890. This work was started by Sanborn, who, upon his retirement to become director at the Utah station, started the same kind of work at the latter place.

In 1898 and 1899 the South Carolina station made tests of various methods of planting and depths of cultivation, and included a plat that was weeded but not cultivated.

The results of all these experiments, with the exception of those in Utah, are shown in Table I.

TABLE I.—*Results of early experiments in corn tillage.*

| Location of State experiment station. | Year. | Yield per acre. | | | | Yield of uncultivated plat expressed as percentage of cultivated. | | Precipitation. | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Cultivated plats. | | Uncultivated plats. | | | | For last 3 months of preceding and first 9 months of current year. | Mean. | Comparison with mean. |
| | | Fodder. | Grain. | Fodder. | Grain. | Fodder. | Grain. | | | |
| | | *Lbs.* | *Bush.* | *Lbs.* | *Bush.* | | | *Inches.* | *Inches.* | *Per ct.* |
| Geneva, N. Y.[1] | 1886 | ........ | 56.8 | ........ | 70.5 | ........ | 124.1 | 32.66 | 32.81 | 99.5 |
| Urbana, Ill.[2] | 1888 | ........ | 93.8 | ........ | 90.0 | ........ | 95.9 | 40.11 | 35.74 | 112.2 |
| | 1889 | ........ | 84.6 | ........ | 77.1 | ........ | 91.1 | 41.74 | | 116.7 |
| | 1890 | ........ | 66.8 | ........ | 69.1 | ........ | 103.4 | 39.16 | | 109.5 |
| | 1891 | ........ | 58.4 | ........ | 55.3 | ........ | 94.7 | 25.09 | | 70.2 |
| | 1892 | ........ | 70.1 | ........ | 76.8 | ........ | 109.5 | 42.70 | | 119.4 |
| | 1893 | ........ | 36.3 | ........ | 28.7 | ........ | 79.0 | 37.72 | | 105.5 |
| | 1896 | ........ | 85.5 | ........ | 87.0 | ........ | 101.7 | 40.00 | | 111.9 |
| Columbia, Mo.[3] | 1889 | 3,920 | 80.1 | 3,900 | 82.0 | 99.5 | 101.3 | 42.34 | 38.46 | 110.0 |
| | 1890 | 2,205 | 54.0 | 1,570 | 45.7 | 71.2 | 84.6 | 40.86 | | 106.2 |
| Clemson College, S. C.[4] | 1898 | ........ | 58.6 | ........ | 56.5 | ........ | 96.4 | 48.35 | 51.14 | 94.6 |
| | 1899 | ........ | 67.3 | ........ | 67.5 | ........ | 100.3 | 50.11 | | 98.0 |
| Total | ...... | 6,125 | 812.3 | 5,470 | 806.2 | ........ | ........ | 480.84 | ........ | ........ |
| Average | ...... | 3,062 | 67.69 | 2,735 | 67.18 | 85.35 | 98.5 | 40.07 | 38.51 | 104.4 |

[1] Annual Report, 1886, p. 46.
[2] Illinois Bulletins 20, 25, 31, 46.
[3] Missouri Bulletin 14.
[4] South Carolina Bulletin 61.

## EXPERIMENTS IN UTAH.

Table II shows the results of seven years' work covering experiments on corn cultivation made at the Utah Agricultural Experiment Station, as recorded in Bulletin No. 66 of that station. As these experiments were made under irrigation conditions, the data are not included in the discussions of the other early experiments or in the résumé on page 24. It is apparent that the "no tillage" treat-

ment did not receive a fair trial, since, to quote the bulletin mentioned, page 129, "the weed pulling by hand loosened the soil to a considerable extent, for they were not pulled until large enough to be easily taken hold of, and they were always plentiful." In a recent letter Prof. Sanborn describes the treatment of the "scarified" plats, showing that it was practically identical with the nontilled treatment of our work. In this connection, therefore, the scarified plats should be compared with either the shallow-tilled or medium-tilled plats.

It will be noted in Table II that the average figures of all the years for the scarified plats is 58.87 bushels of grain and 3,036 pounds of fodder, as compared with 52.91 bushels of grain and 3,487 pounds of fodder for the shallow-tilled plats and 57.31 bushels of grain and 3,431 pounds of fodder for the medium-tilled plats.

TABLE II.—*Results of experiments in corn tillage in Utah.*

| Year. | Yield per acre. | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Shallow tillage. | | Medium tillage. | | Deep tillage. | | No tillage. | | Mulched with dirt. | | Scuffle hoe (scarified). | |
| | Fodder. | Grain. | Fodder. | Grain. | Fodder. | Grain. | Fodder. | Grain. | Fodder. | Grain. | Fodder. | Grain. |
| | *Pounds.* | *Bush.* | *Pounds.* | *Bush.* | *Pounds.* | *Bush.* | *Pounds.* | *Bush.* | *Pounds.* | *Bush.* | *Pounds.* | *Bush.* |
| 1890, 1892 [1] | 1,704 | 16.75 | 1,981 | 15.80 | 1,169 | 27.08 | 1,574 | 12.35 | 1,270 | 16.69 | 2,286 | 23.10 |
| 1893 | 1,666 | 37.52 | 2,433 | 54.18 | 2,866 | 61.11 | 2,933 | 67.23 | 2,844 | 76.18 | 2,000 | 43.60 |
| 1894 | 2,800 | 51.81 | 3,467 | 69.22 | 3,067 | 52.76 | 3,600 | 52.38 | 3,067 | 56.38 | 2,800 | 57.33 |
| 1895 | ........ | 57.14 | ........ | 54.09 | ........ | 50.67 | ........ | 63.43 | ........ | 60.75 | ........ | 72.19 |
| 1896 | 8,067 | 79.04 | 6,606 | 75.14 | 9,600 | 66.66 | 6,227 | 71.05 | 8,160 | 76.57 | 4,360 | 69.33 |
| 1897 | 3,200 | 75.22 | 2,667 | 75.41 | 1,867 | 79.41 | 2,667 | 44.75 | 3,467 | 48.75 | 3,733 | 77.69 |
| Average | 3,487 | 52.91 | 3,431 | 57.31 | 3,714 | 57.45 | 3,400 | 51.86 | 3,762 | 55.89 | 3,036 | 58.87 |

[1] Average for the two years.

## EXPERIMENTS OF THE BUREAU OF PLANT INDUSTRY.

In 1905 the senior writer collected the early data of the State agricultural experiment stations and conducted a test on corn cultivation at Ithaca, N. Y. On becoming a member of the staff of the Department of Agriculture he carried on similar tests in 1906 in cooperation with three experiment stations and in 1907 with four stations, one individual, and the Arlington Experimental Farm of the Department. In 1908 the work was conducted by four stations, one individual, and the test farm at Arlington. In 1909, 1910, and 1911 it was carried on in cooperation with various farmers in different parts of the United States.

Figure 3 shows the shocked corn from the plats at the Arlington Experimental Farm in 1908. One of the shocks is from a cultivated plat, the next one from an uncultivated plat, and thus alternating through the series. Figure 4 shows the ear corn from the same

experiment, one pile being from a cultivated plat, the next one from an uncultivated plat, and thus alternating. Figure 5 illustrates the

FIG. 3.—Shocks from the corn experiment at the Arlington Experimental Farm, 1908. The shock at the right is from a cultivated plat, the next one from an uncultivated plat, and so on.

experiment of Mr. J. J. Lee, Cynthiana, Ky., in 1909, showing the uncultivated plat and the cultivated plat. Figure 6 shows the

FIG. 4.—Ears of corn from the same shocks shown in figure 3. The corn at the left was cultivated, that in the next pile uncultivated, and so on.

fodder and ear corn from the experiment of Mr. Geoffrey Morgan, Whites Station, Ky., in 1910, both cultivated and uncultivated.

FIG. 5.—Cultivated and uncultivated plats of corn, the experiment of Mr. J. J. Lee, Cynthiana, Ky., in 1909. The uncultivated plat is shown in the left half of the illustration and the cultivated plat on the right.

FIG. 6.—Cultivated and uncultivated fodder and ears of corn, the experiment of Mr. Geoffrey Morgan, Whites Station, Ky., in 1910. The cultivated fodder and corn are at the left of the illustration and the uncultivated at the right.

Figure 7 represents one of the three pairs of uncultivated and cultivated plats at Arlington in 1911, photographed just before tasseling.

A number of experiments were carefully conducted up to a certain point and were then discontinued for various reasons, such as stock

FIG. 7.—One of three pairs of corn plats at the Arlington Experimental Farm in 1911. The uncultivated corn is at the left and the cultivated at the right.

breaking in, storms blowing down the corn, or the plats being harvested together by mistake. Of 15 such discontinued experiments 8 showed practically no difference between the cultivated and uncultivated plats at the time of the discontinuance; 4 were in favor of the uncultivated and 3 in favor of the cultivated treatment.

Table III gives the data for the seven years 1905 to 1911.

TABLE III.—*Results of experiments in corn tillage for the years 1905 to 1911, inclusive.*

| Name and address of experimenter. | Year. | Yield per plat. Cultivated. Fodder. | Yield per plat. Cultivated. Grain. | Yield per plat. Uncultivated. Fodder. | Yield per plat. Uncultivated. Grain. | Yield of uncultivated plat expressed as percentage of cultivated. Fodder. | Yield of uncultivated plat expressed as percentage of cultivated. Grain. | Size of plat. | Yield per acre (calculated). Cultivated plats. Fodder. | Yield per acre (calculated). Cultivated plats. Grain. | Yield per acre (calculated). Uncultivated plats. Fodder. | Yield per acre (calculated). Uncultivated plats. Grain. | Precipitation. Last 3 months of preceding and first 9 months of current year. | Precipitation. Mean. | Precipitation. Comparison with mean. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *Lbs.* | *Lbs.* | *Lbs.* | *Lbs.* | | | *Acres.* | *Lbs.* | *Bush.* | *Lbs.* | *Bush.* | *Ins.* | *Ins.* | *P. ct.* | |
| Cates, J. S., Ithaca, N. Y.: | | | | | | | | | | | | | | | | |
| Plat 1 | 1905 | 33 | 35 | 29 | 32 | 87.8 | 91.4 | ...... | ...... | ...... | ...... | ...... | 35.05 | 32.97 | 94 | Rolling land. |
| Plat 2 | 1905 | 29 | 28 | 26 | 28 | 89.6 | 100 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | Level land. |
| Michigan experiment station, East Lansing, Mich. | 1906 | ...... | 473 | ...... | 535 | ...... | 113.1 | ...... | ...... | ...... | ...... | ...... | 28.94 | 30.99 | 107 | |
| New Hampshire experiment station, Durham, N. H. | 1906 | 1,960 | 1,631 | 2,190 | 2,310 | 111.7 | 141.6 | ...... | 1,960 | 23.3 | 2,190 | 33 | 39.73 | 40.67 | 102.3 | |
| Purdue experiment station, Lafayette, Ind. | 1906 | ...... | 370 | ...... | 355 | ...... | 95.9 | 0.1125 | ...... | 46.97 | ...... | 45.04 | 38.17 | 36.83 | 96.5 | |
| Total | ...... | 2,022 | 2,537 | 2,245 | 3,260 | ...... | ...... | .1125 | 1,960 | 70.27 | 2,190 | 78.04 | ...... | ...... | ...... | |
| Average | ...... | 674 | 507.4 | 748.3 | 652 | 96.36 | 108.4 | .1125 | ...... | 35.13 | ...... | 39.02 | 35.47 | 35.36 | 99.95 | |
| Arlington Experimental Farm, Rosslyn, Va.: | | | | | | | | | | | | | | | | |
| Plat 1 | 1907 | ...... | 104.04 | ...... | 123.76 | ...... | 118.9 | ...... | ...... | ...... | ...... | ...... | 44.73 | 40.80 | 109.6 | Clay soil; planted 3.3 by 3.3 feet. |
| Plat 2 | 1907 | ...... | 157.41 | ...... | 134.64 | ...... | 85.5 | ...... | ...... | ...... | ...... | ...... | | | | Gently sloping; planted in rows 3.3 feet apart, half that distance between hills. |
| Cornell experiment station, Ithaca, N. Y. | 1907 | ...... | 3,522 | ...... | 3,643 | ...... | 103.4 | ...... | ...... | 50.3 | ...... | 52.0 | 33.25 | 32.97 | 100.7 | Rather sandy; rolling. |
| Froley, J. W., Springfield, Md. | 1907 | ...... | 151 | ...... | 165 | ...... | 109.2 | .033 | ...... | 65.3 | ...... | 71.3 | 40.13 | 41.80 | 96 | |
| Michigan experiment station, East Lansing, Mich.: | | | | | | | | | | | | | | | | |
| Plat 1 | 1907 | 270 | 287 | 243 | 471 | 89.6 | 164.1 | ...... | ...... | ...... | ...... | ...... | 33.18 | 30.99 | 107 | Sandy, gravelly loam; Rustler. |
| Plat 2 | 1907 | 251.7 | 225 | 235.6 | 225 | 93.6 | 100 | ...... | ...... | ...... | ...... | ...... | | | | Level; Silver King. Spring cold and wet. |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Nebraska experiment station, Lincoln, Nebr. | 1907 | ...... | 4,333 | ...... | 4,417 | ...... | 101.9 | ...... | ...... | 61.9 | ...... | 63.1 | 28.41 | 27.51 | 103.2 | Alfalfa sod; good soil. |
| Purdue experiment station, Lafayette, Ind. | 1907 | ...... | 1,077.5 | ...... | 1,118 | ...... | 103.7 | .2 | ...... | 77 | ...... | 79.8 | 38.44 | 36.83 | 104.3 | Extremely wet. |
| Total | ...... | 521.7 | 9,856.95 | 478.6 | 10,297.4 | ...... | ...... | .233 | ...... | 254.5 | ...... | 266.2 | ...... | ...... | ...... | |
| Average | ...... | 260.8 | 1,232.12 | 239.3 | 1,287.17 | 91.6 | 110.84 | .1165 | ...... | 63.6 | ...... | 66.55 | 36.36 | 35.15 | 103.47 | |
| Arlington Experimental Farm, Rosslyn, Va. | 1908 | 197.5 | 290 | 186 | 283.5 | 94.2 | 97.7 | .10 | 1,975 | 41.4 | 1,860 | 40.5 | 42.86 | 40.80 | 105 | Clay; slightly sloping. |
| Campbell, J. M., Richardson, Tex. | 1908 | 285 | 264 | 251 | 268 | 88 | 101.5 | ...... | ...... | ...... | ...... | ...... | 46.39 | 42.62 | 108.7 | Black waxy soil; level. |
| Minnesota experiment station, St. Paul, Minn. | 1908 | 270 | 450 | 270 | 450 | 100 | 100 | .10 | 2,700 | 62.5 | 2,700 | 62.5 | 29.99 | 27.80 | 107.7 | Sandy loam; average season. |
| New Hampshire experiment station, Durham, N. H. | 1908 | 4,980 | 4,953 | 4,860 | 4,974 | 97.6 | 100.4 | ...... | 4,980 | 67.9 | 4,860 | 68.2 | 43.09 | 40.67 | 105.8 | |
| North Carolina experiment station, W. Raleigh, N. C. | 1908 | ...... | 808.5 | ...... | 744.1 | ...... | 92 | ...... | ...... | 11.55 | ...... | 10.63 | 61.05 | 49.47 | 123.2 | Raw, poor, black-jack clay. |
| Purdue experiment station, Lafayette, Ind. | 1908 | ...... | 4,375 | ...... | 4,200 | ...... | 96 | ...... | ...... | 62.5 | ...... | 60 | 33.06 | 36.83 | 89.8 | |
| Total | ...... | 5,732.5 | 11,140.5 | 5,567 | 10,919.6 | ...... | ...... | .20 | 9,655 | 245.85 | 9,420 | 241.83 | ...... | ...... | ...... | |
| Average | ...... | 1,433.1 | 1,856.8 | 1,391.7 | 1,819.9 | 94.95 | 97.93 | .10 | 3,218 | 49.17 | 3,140 | 48.36 | 42.74 | 39.69 | 106.7 | |
| Anderson, W. B., Velpen, Ind. | 1909 | (1) | 337 | (1) | 460 | ...... | 136.5 | .10 | ...... | 48.1 | ...... | 65.65 | 35.80 | 40.77 | 87.9 | Yellow clay, rolling; wet early part of season. |
| Arlington Experimental Farm, Rosslyn, Va. | 1909 | 445 | 321 | 408 | 238 | 91.7 | 74.1 | .15 | 2,966 | 30.6 | 2,720 | 22.7 | 34.42 | 40.80 | 84.4 | Stiff clay, packed hard; sloping; period of drought during summer. |
| Barrett, J. M., Napton, Mo. | 1909 | (1) | 190 | (1) | 235 | ...... | 123.7 | .052 | ...... | 52.2 | ...... | 64.57 | 39.78 | 36.50 | 108.9 | Silt loam, level; fairly good season, except 5 weeks dry weather after July 27. |
| Callison, N. A., Gainesville, Fla. | 1909 | 710 | 580 | 680 | 505 | 95.8 | 87.1 | .327 | 2,171 | 25.3 | 2,077 | 22.02 | 39.73 | 51.34 | 77.4 | Sandy loam, level; rather dry season. |
| Campbell, J. M., Richardson, Tex. | 1909 | ...... | 214 | ...... | 143 | ...... | 66.8 | .250 | ...... | 12.2 | ...... | 8.15 | 16.18 | 39.04 | 41.4 | Black waxy, level; very dry season. |
| Cunningham, T. J., Chester, S. C. | 1909 | [2] 27 | 173 | 27 | 199 | 100 | 115 | .096 | ...... | 22.5 | ...... | 25.9 | 47.99 | 49.13 | 97.6 | Gravel, clay subsoil; rolling land; wet season. |
| Day, A. P., West Kennebunk, Me. | 1909 | [1] 665 | ...... | [1] 575 | ...... | 86.5 | ...... | .154 | ...... | ...... | ...... | ...... | 37.36 | 42.63 | 87.6 | Sandy loam, clay subsoil, sloping slightly; extremely dry season. |
| Dimond, O. C., West Concord, N. H. | 1909 | 153 | 166 | [3] 180 | 201 | 121.5 | 121.1 | .038 | 4,050 | 62.4 | 4,891 | 75.6 | 30.14 | 39.82 | 75.7 | Strong loam; hill land, with gentle slope; rather dry season. |
| Foster, W. L., Shreveport, La. | 1909 | (1) | 375 | (1) | 430 | ...... | 114.7 | .322 | ...... | 16.6 | ...... | 19.04 | 29.64 | 45.45 | 65.2 | Sandy loam, level; wet in early part of season. |
| Lambert, F. L., Charles City, Iowa. | 1909 | ...... | 261 | (4) | 301 | ...... | 115.3 | .066 | ...... | 56.4 | ...... | 65 | 36.57 | 31.29 | 116.8 | Sandy loam, level; good season. |
| Lee, J. J., Cynthiana, Ky. | 1909 | [4] 555 | 494 | 547 | 474 | 98.5 | 96 | .0868 | 6,393 | 81.3 | 6,298 | 78 | 47.08 | 43.99 | 107.2 | Dark loam, level; wet season. |

[1] No difference in time of ripening. [2] Ripened slightly earlier. [3] Ripened a few days earlier. [4] Ripened earlier.

TABLE III.—*Results of experiments in corn tillage for the years 1905 to 1911, inclusive*—Continued.

| Name and address of experimenter. | Year. | Yield per plat. | | | | Yield of uncultivated plat expressed as percentage of cultivated. | | Size of plat. | Yield per acre (calculated). | | | | Precipitation. | | | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Cultivated. | | Uncultivated. | | | | | Cultivated plats. | | Uncultivated plats. | | Last 3 months of preceding and first 9 months of current year. | Mean. | Comparison with mean. | |
| | | Fodder. | Grain. | Fodder. | Grain. | Fodder. | Grain. | | Fodder. | Grain. | Fodder. | Grain. | | | | |
| | | *Lbs.* | *Lbs.* | *Lbs.* | *Lbs.* | | | *Acres.* | *Lbs.* | *Bush.* | *Lbs.* | *Bush.* | *Ins.* | *Ins.* | *P. ct.* | |
| Leffler, G. V., Stockport, Iowa. | 1909 | ........ | 156 | ........ | 171 | ...... | 109.6 | 0.055 | ...... | 40.5 | ........ | 44.4 | 32.44 | 34.97 | 92.8 | Heavy loam, level; rather dry season. |
| Littlejohn, W. D., Kentland, Ind. | 1909 | ........ | 171 | (1) | 163 | ...... | 95.3 | .0331 | ...... | 73.8 | ........ | 70.4 | 48.08 | 36.13 | 133 | Black sandy loam, level; wet season. |
| McCune, Kate B., Shedd, Oreg. | 1909 | (2) | 47 | (2) | 50 | ...... | 106.3 | .0062 | ...... | 107.4 | ........ | 114.2 | ........ | ...... | ...... | Clay loam, level; rather dry season. |
| Merwin, G. H., Southport, Conn. | 1909 | (2) | 540 | (2) | 540 | ...... | 100 | .0984 | ...... | 78.4 | ........ | 78.4 | 42.20 | 45.89 | 92 | Heavy loam, level; fairly good season. |
| Perry, J. B., Clarks Falls, Conn. | 1909 | [1] 331 | 264.5 | 320.5 | 287.7 | 96.8 | 108.7 | .0827 | 4,002 | 45.7 | 3,872 | 49.6 | 45.84 | 46.18 | 99.4 | Light loam, hardpan, gravelly subsoil, level; dry season. |
| Purdue experiment station, Lafayette, Ind. | 1909 | ........ | 2,940 | ........ | 2,947 | ...... | 100.25 | ........ | ...... | 42 | ........ | 42.1 | 46.80 | 36.83 | 127 | |
| Rich, E. A. J., Brinson, Ga. | 1909 | 342 | 309 | 373 | 429 | 109 | 138.8 | .1446 | 2,365 | 26.7 | 2,579 | 37.04 | 36.10 | 49.90 | 72.3 | Sandy loam, level; rather dry season. |
| Sawyer, R. S., Walpole, N. H. | 1909 | ........ | 785 | ........ | 542 | ...... | 69.1 | .1572 | ...... | 71.3 | ........ | 49.2 | 36.77 | 41.04 | 89.5 | Do. |
| Seay, Robt., Emporia, Va. | 1909 | [2] 160 | 201 | [2] 169 | 162 | 105.6 | 80.6 | .0965 | 1,658 | 29.7 | 1,751 | 23.95 | 50.47 | 45.89 | 110 | Sandy loam, level; dry. |
| Sugar experiment station, New Orleans, La. | 1909 | (2) | 99.3 | (2) | 99.3 | ...... | 100 | .0602 | ...... | 20.6 | ........ | 20.6 | 59.23 | 55.63 | 106.4 | Heavy sandy loam, level; average season. |
| Tenney, W. P., Chester, N. H. | 1909 | (2) | 425 | (2) | 725 | ...... | 170.5 | .1944 | ...... | 31.25 | ........ | 53.2 | 30.14 | 39.82 | 75.7 | Medium to light loam, level; very dry season. |
| Wallace, M., Marion, S. C. | 1909 | (2) | 2,947 | (2) | 2,709 | ...... | 91.9 | .496 | ...... | 84.9 | ........ | 78 | 40.24 | 46.55 | 86.5 | Clay, level; season a little dry. |
| Watson, D. A., Durham, N. H. | 1909 | ........ | 238 | ........ | 236 | ...... | 99.1 | .0505 | ...... | 67.4 | ........ | 66.8 | 33.79 | 42.17 | 80.2 | Fine clay loam, sloping; season dry and cold. |
| Welch, E. K., Northwood Center, N. H. | 1909 | [2] 302 | 170 | [2] 320.5 | 186.5 | 106.1 | 109.7 | .0378 | ...... | 64.2 | ........ | 70.4 | 30.14 | 39.82 | 75.7 | Sandy loam, gravelly with hardpan subsoil; hilly; season unfavorable. |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wollschlaeger, Gus, Boerne, Tex. | 1909 | (2) | 340 | (2) | 346 | ....... | 101.7 | .253 | ....... | 19.2 | ......... | 19.55 | 22.26 | 31.42 | 70.9 | Black waxy, hilly; very dry season. |
| Total | ...... | 3,690 | 12,743.8 | 3,606 | 12,779.5 | ....... | ....... | 3.4074 | 23,605 | 1,210.65 | 24,188 | 1,264.83 | ......... | ...... | ....... | |
| Average | ...... | 369 | 509.7 | 360.6 | 511.2 | 101.15 | 105.27 | .1363 | 3,372 | 48.42 | 3,455 | 50.59 | 37.96 | 42.13 | 90.46 | |
| Anderson, W. B., Velpen, Ind. | 1910 | ........ | 804 | ........ | 798 | ....... | 99.2 | .1285 | ....... | 62.6 | ......... | 62.2 | 40.47 | 40.77 | 99.4 | Light clay, level; season very wet. |
| Bigstaff, T. J., Mount Sterling, Ky. | 1910 | 6,890 | 2,680 | [1] 6,300 | 2,590 | 91.4 | 96.6 | 1.016 | 4,145 | 37.65 | 3,650 | 36.39 | 61.85 | 48.10 | 128.6 | Clay loam, gently rolling; season very wet. |
| Brant, W. C., Ruffin, S. C. | 1910 | [2] 130.75 | 141.25 | [2] 184 | 135 | 140.6 | 95.5 | .0287 | 4,550 | 70.3 | 6,408 | 67.2 | 47.84 | 50.02 | 95.7 | Light sandy, level; heavy rains. |
| Campbell, J. M., Richardson, Tex. | 1910 | ........ | 115.7 | ........ | 124 | ....... | 107.1 | .0689 | ....... | 24 | ......... | 25.71 | 27.74 | 39.04 | 71.1 | Black waxy, level; very dry; less than 4 inches of rain after planting. |
| Case, J. H., Lawrenceburg, Ky | 1910 | ........ | 4,550 | (1) | 4,900 | ....... | 107.7 | | ....... | 65 | ......... | 70 | 46.03 | 43.58 | 105.7 | Uniform clay loam, hilly. |
| Crum, H. C., Denmark, S. C. | 1910 | (1) | 168.7 | ........ | 192.8 | ....... | 114.3 | 1.1147 | ....... | 21 | ......... | 24 | 41.09 | 47.89 | 85.8 | Sandy loam, red clay subsoil; too much rain. |
| Dailey, S. C., North Baltimore, Ohio. | 1910 | 904 | 1,347 | [3] 872 | 1,202 | 96.4 | 89.2 | .2315 | 3,900 | 83.1 | 3,765 | 74.1 | 35.18 | 38.35 | 91.7 | Loose black soil, level; fair season, but dry in August. |
| Day, A. P., West Kennebunk, Me. | 1910 | 164 | 146 | 153 | 127 | 93.3 | 87 | .0413 | 3,970 | 47.9 | 3,705 | 41.7 | 32.10 | 42.63 | 75.3 | Clay loam, gently sloping; favorable season. |
| Dimond, O. C., West Concord, N. H. | 1910 | [1] 300 | 274 | 254 | 249 | 84.6 | 90.9 | .0432 | 6,950 | 90.6 | 5,875 | 82.4 | 29.59 | 39.82 | 74.3 | Strong loam, rolling; wet early; dry late. |
| Elmer, E. O., Devereaux, Mich. | 1910 | [2] 68.9 | 118 | [2] 67.9 | 120.2 | 98.6 | 101.8 | .0197 | 3,497 | 85.6 | 3,448 | 87.1 | 30.83 | 33.33 | 92.6 | Clay loam, level; wet and cold after planting; very dry during July. |
| Ferguson, A. M., Sherman, Tex. | 1910 | ........ | 86 | ........ | 82.5 | ....... | 95.9 | .2169 | ....... | 5.67 | ......... | 5.43 | 22.09 | 38.25 | 57.7 | Black waxy, some sand; very dry during growing period. |
| Finley, W. W., North Wilkesboro, N. C. | 1910 | ........ | 392 | (1) | 362 | ....... | 92.3 | .1147 | ....... | 48.8 | ......... | 45.1 | 46.23 | 57.63 | 80.2 | Red clay, level; rainy in June, dry in July. |
| Fredericks, C. P., Sunbury, Ohio. | 1910 | 189 | 161.2 | [4] 168.8 | 171.4 | 89.3 | 106.4 | .0459 | 4,120 | 50.14 | 3,680 | 53.34 | 33.48 | 36.08 | 91.3 | Clay loam, level; fair season. |
| Gardner, E. T., Fowler, Colo. | 1910 | [2] 144.4 | 71.8 | [2] 128.2 | 64.7 | 88.8 | 90.1 | .0632 | 2,288 | 16.2 | 2,032 | 14.62 | ......... | 12.98 | ....... | Loam, gently sloping; season dry; one irrigation. |
| George, H. C., Okeana, Ohio. | 1910 | ........ | 1,150 | ........ | 1,035 | ....... | 90 | .2963 | ....... | 55.4 | ......... | 49.9 | 31.98 | 40.91 | 78.1 | Clay loam; bottom land; season rather wet. |
| Goddard, W. R., Amesville, Ohio. | 1910 | ........ | 360 | (1) | 336 | ....... | 93.3 | .0606 | ....... | 84.9 | ......... | 79.2 | 29.40 | 39.37 | 74.8 | Black clay, level; bottom land; very dry season. |
| Hansbarger, D., Ansonia, Ohio. | 1910 | (1) | 6,060 | ........ | 6,023 | ....... | 99.4 | 8.22 | ....... | 105.4 | ......... | 104.8 | 37.06 | 36.97 | 100.2 | Black, fairly loose soil, level; dry toward last of season. |
| Hester, H. C., Mayfield, Ky. | 1910 | [5] 330 | 250 | 180 | 210 | 54.5 | 84 | .0482 | 6,850 | 74.1 | 3,730 | 62.2 | 49.65 | 48.63 | 102.1 | Loose clay loam, level; no rain till roasting-ear stage; then very wet. |
| Heuser, W. L., Haymarket, Va. | 1910 | [2] 102 | 136 | [2] 81 | 112 | 79.4 | 82.4 | .0397 | 2,570 | 48.9 | 2,038 | 40.3 | 38.54 | 38.02 | 101.2 | Red shale soil, level; wet early, dry later. |

[1] Ripened earlier. [2] No difference in the time of ripening. [3] Ripened 3 days earlier. [4] Ripened 5 days earlier. [5] Ripened a few days earlier.

TABLE III.—*Results of experiments in corn tillage for the years 1905 to 1911, inclusive*—Continued.

| Name and address of experimenter. | Year. | Yield per plat. | | | | Yield of uncultivated plat expressed as percentage of cultivated. | | Size of plat. | Yield per acre (calculated). | | | | Precipitation. | | | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Cultivated. | | Uncultivated. | | | | | Cultivated plats. | | Uncultivated plats. | | Last 3 months of preceding and first 9 months of current year. | Mean. | Comparison with mean. | |
| | | Fodder. | Grain. | Fodder. | Grain. | Fodder. | Grain. | | Fodder. | Grain. | Fodder. | Grain. | | | | |
| | | *Lbs.* | *Lbs.* | *Lbs.* | *Lbs.* | | | *Acres.* | *Lbs.* | *Bush.* | *Lbs.* | *Bush.* | *Ins.* | *Ins.* | *P. ct.* | |
| Howle, P. L., Darlington, S. C. | 1910 | ([1]) | 78.1 | ([1]) | 75.81 | | 97.1 | 0.0744 | | 15 | | 14.56 | 39.53 | 47.20 | 83.8 | Sandy, with clay subsoil; fairly good season. |
| Huyett, J. B., Charles Town, W. Va. | 1910 | ([1]) | 323.6 | ([1]) | 225.5 | | 69.7 | .1398 | | 33.1 | | 23.08 | 27.52 | 37.43 | 73.6 | Loam, with clay subsoil; extremely dry season. |
| Kirkpatrick, L. R., McKinney, Tex. | 1910 | | 448.7 | ([2]) | 308 | | 68.4 | .1687 | | 38 | | 26 | 27.74 | 49.96 | 55.6 | Black loam; low bottom, extremely dry season. |
| Lambert, F. L., Charles City, Iowa. | 1910 | ([1]) | 213.7 | ([1]) | 213.7 | | 100 | .0555 | | 55 | | 55 | 25.04 | 31.29 | 80.1 | Sandy loam, level; dry at first; wet later. |
| Lemmon, R. H., Winnsboro, S. C. | 1910 | ([1]) | 52 | ([1]) | 52 | | 100 | .0155 | | 47.9 | | 47.9 | 41.85 | 44.61 | 93.8 | Sandy loam, slightly rolling; wet season. |
| Lloyd, F. L., Smithville, Ky. | 1910 | ([2]) | 62.5 | | 63.5 | | 101.6 | .01406 | | 63.5 | | 64.4 | 48.29 | 45.67 | 105.6 | Heavy clay, rolling; wet season. |
| McClelland, C. K., Prescott, Ark. | 1910 | ([2]) | 64.2 | | 49.7 | | 77.4 | .0884 | | 10.37 | | 8.03 | 47.56 | 44.94 | 105.7 | Heavy clay, nearly level; very dry most of season. |
| McCulloch, Fred, Hartwick, Iowa. | 1910 | 77.5 | 213.5 | 75 | 202 | 96.8 | 94.6 | | | | | | 25.43 | 34.48 | 73.9 | Season very dry and hot. |
| McCune, Kate B., Shedd, Oreg. | 1910 | ([1]) | 13 | ([1]) | 12 | | 92.3 | .00284 | | 65.2 | | 60.3 | | | | Clay loam; season very dry. |
| Marvin, Jas. A., Hendersonville, S. C. | 1910 | | 497 | ([2]) | 518 | | 104.2 | .297 | | 23.9 | | 24.9 | 47.84 | 50.02 | 95.6 | Sandy soil, clay subsoil; latter part of season very wet. |
| Morgan, Geoffrey, Whites Station, Ky. | 1910 | [2] 650 | 705 | 700 | 820 | 107.7 | 116.3 | .1027 | 6,330 | 98.1 | 6,820 | 114.1 | 50.22 | 44.02 | 114 | Loam soil, clay subsoil; very wet season. |
| Nichols, W. D., Bloomfield, Ky. | 1910 | 177 | 171 | 118 | 126 | 66.6 | 73.7 | | | | | | 48.39 | 44.90 | 107.7 | Clay loam, gently sloping; rather dry early, very wet later. |
| Perry, John B., Clarks Falls, Conn. | 1910 | [1] 364 | 320 | [1] 368 | 323 | 101.1 | 100.9 | .1077 | 3,376 | 42.45 | 3,415 | 42.82 | 36.89 | 46.18 | 79.9 | Light loam, level; good season. |
| Ratliff, W. S., Richmond, Ind. | 1910 | 126.5 | 92 | 114.5 | 114 | 90.5 | 123.9 | .0313 | 4,040 | 42 | 3,656 | 52 | 37.62 | 38.49 | 97.8 | Sandy loam, clay subsoil; rather dry season. |
| Rector, J. H., Cumberland Gap, Tenn. | 1910 | 260 | 350 | [2] 300 | 330 | 115.4 | 94.3 | .0358 | 7,260 | 139.7 | 8,380 | 131.7 | 44.11 | 48.33 | 91.4 | Clay soil, level; very wet season. |
| Rinehart, N. W., Union, Ohio | 1910 | ([1]) | 545.5 | ([1]) | 459.5 | | 84.2 | .0745 | | 104.6 | | 88 | 32.63 | 36.55 | 89.4 | Rich, black, level bottom. |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ross, Henry, Milford, Mich. | 1910 | [1] 490 | 450 | [1] 445 | 445.3 | 90.8 | 99 | .208 | 2,353 | 30.9 | 2,136 | 30.6 | 28.04 | 31.77 | 88.3 | Clay loam, sloping; season rather dry. |
| Royse, Oscar, Shenandoah, Iowa. | 1910 | ........ | 108.5 | ........ | 120.75 | ....... | 111.2 | .0312 | ....... | 49.65 | ......... | 55.25 | 30.83 | 32.25 | 95.6 | |
| Sugar Experiment Station, New Orleans, La. | 1910 | (1) | 258 | (1) | 295.8 | ....... | 114.7 | .1206 | ....... | 30.5 | ......... | 35 | 55.12 | 55.63 | 99.1 | Heavy alluvial silt; average season except long drought in spring. |
| U. S. Plant Introduction Garden, Chico, Cal. | 1910 | (1) | 52.5 | (1) | 46 | ....... | 87.6 | .0603 | ....... | 12.4 | ......... | 10.9 | 21.84 | 23.39 | 93.4 | Sandy loam, level; season very dry. |
| Welch, E. K., Northwood Center, N. H. | 1910 | [1] 243 | 187 | [1] 329 | 236 | 135.4 | 126.2 | .0379 | 6,410 | 70.5 | 8,670 | 89 | 29.59 | 39.82 | 74.3 | Sandy loam, hilly; season rather dry. |
| Williams, D. W., Wauseon, Ohio. | 1910 | [1] 850 | 881 | [1] 902.5 | 888.5 | 106.5 | 100.8 | .1185 | 7,174 | 106.2 | 7,641 | 106.9 | 36.04 | 37.31 | 96.6 | Clay and sand, good soil; season rather dry. |
| Winsor, B. E., Coventry, R. I. | 1910 | (1) | 351.5 | (1) | 315 | ....... | 89.6 | .0689 | ....... | 72.9 | ......... | 65.3 | 33.61 | 45.31 | 74.2 | Sandy loam, hilly; season very dry. |
| Wollschlaeger, Gus, Boerne, Tex. | 1910 | (1) | 452 | (1) | 448.7 | ....... | 99.3 | .2712 | ....... | 23.78 | ......... | 23.6 | 19.73 | 31.42 | 62.8 | Black waxy, level; season very dry. |
| Total | ...... | 12,461 | 25,901.95 | 11,740.9 | 25,523.3 | ....... | ....... | 6.525 | 79,783 | 2,252.91 | 79,049 | 2,195.03 | ......... | ...... | ...... | |
| Average | ...... | 655.8 | 602.3 | 617.9 | 593.5 | 96.19 | 96.51 | .1591 | 4,693 | 54.95 | 4,650 | 53.54 | 36.99 | 41.8 | 88.7 | |
| Anderson, W. B., Velpen, Ind. | 1911 | (1) | 1,040 | (1) | 1,014 | ....... | 97.5 | .20 | ....... | 74.3 | ......... | 72.4 | ......... | ...... | ...... | Loose bottom land, level; very wet except in midsummer, when it was very dry. |
| Arlington Experimental Farm, Rosslyn, Va. | 1911 | 982 | 824 | 1,110 | 608 | 113 | 73.9 | .15 | 6,545 | 78.4 | 7,400 | 58 | ......... | ...... | ...... | |
| Brant, W. C., Ruffin, S. C. | 1911 | 910 | 565 | 925 | 590 | 101.6 | 104.4 | .241 | 3,775 | 33.5 | 3,839 | 35 | ......... | ...... | ...... | Bottom land, level. |
| Dailey, S. C., North Baltimore, Ohio. | 1911 | 1,200 | 1,270 | [3] 1,160 | 1,185 | 96.6 | 93.3 | .471 | 2,550 | 38.5 | 2,460 | 35.9 | ......... | ...... | ...... | |
| Day, A. P., West Kennebunk, Me. | 1911 | [1] 578 | 705 | [1] 462.5 | 485 | 80 | 68.8 | .1856 | 3,115 | 54.3 | 2,495 | 37.35 | ......... | ...... | ...... | |
| Dimond, O. C., West Concord, N. H. | 1911 | [1] 692 | 547 | [1] 598 | 539 | 86.4 | 98.5 | .1202 | 5,756 | 65 | 4,972 | 64 | ......... | ...... | ...... | Strong, stony loam, on top of hill sloping; dry until midsummer, later part of season wet. |
| Elmer, E. O., Devereaux, Mich. | 1911 | [1] 218 | 337 | [1] 252 | 365.5 | 115.6 | 108.4 | .0757 | 2,880 | 63.6 | 3,330 | 68.9 | ......... | ...... | ...... | Sandy loam, level; early part of season dry, later part wet. |
| Goddard, W. R., Amesville, Ohio. | 1911 | (1) | 562 | (1) | 596 | ....... | 106 | .1234 | ....... | 65 | ......... | 68.9 | ......... | ...... | ...... | Limestone bottom, level; season very dry. |
| Hester, H. C., Mayfield, Ky. | 1911 | 300 | 150 | 120 | 80 | 40 | 53.3 | .3025 | 992 | 7.1 | 397 | 3.78 | ......... | ...... | ...... | Rolling land; season extremely dry. |
| Heuser, W. L., Haymarket, Va. | 1911 | [1] 182 | 223.5 | [1] 168 | 254 | 92.3 | 113.9 | .0804 | 2,263 | 39.7 | 2,089 | 45.25 | ......... | ...... | ...... | Sandy loam, drained bottom; early part of season dry. |
| Hill, L. E., Walterboro, S. C. | 1911 | ........ | 250 | (2) | 220 | ....... | 88 | .317 | ....... | 11.26 | ......... | 9.92 | ......... | ...... | ...... | Light soil, level; season dry. |
| Housekeeper, G. C., Bowling Green, Ohio. | 1911 | ........ | 681 | (3) | 675 | ....... | 99.1 | .1061 | ....... | 91.7 | ......... | 90.8 | ......... | ...... | ...... | Sandy loam, level; season very favorable. |

[1] No difference in time of ripening.   [2] Ripened earlier.   [3] Ripened a few days earlier.

TABLE III.—*Results of experiments in corn tillage for the years 1905 to 1911, inclusive*—Continued.

| Name and address of experimenter. | Year. | Yield per plat. | | | | Yield of uncultivated plat expressed as percentage of cultivated. | | Size of plat. | Yield per acre (calculated). | | | | Precipitation. | | | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Cultivated. | | Uncultivated. | | | | | Cultivated plats. | | Uncultivated plats. | | Last 3 months of preceding and first 9 months of current year. | Mean. | Comparison with mean. | |
| | | Fodder. | Grain. | Fodder. | Grain. | Fodder. | Grain. | | Fodder. | Grain. | Fodder. | Grain. | | | | |
| | | *Lbs.* | *Lbs.* | *Lbs.* | *Lbs.* | | | *Acres.* | *Lbs.* | *Bush.* | *Lbs.* | *Bush.* | *Ins.* | *Ins.* | *P. ct.* | |
| Huyett, J. B., Charles Town, W. Va. | 1911 | 444.5 | 614 | 432 | 529 | 97.3 | 86.1 | 0.152 | 2,923 | 57.7 | 2,848 | 49.7 | ...... | ...... | ...... | Loam, clay subsoil; season fairly favorable. |
| Ladd, E. O., Old Mission, Mich. | 1911 | [1] 817 | 595 | [1] 787 | 758 | 96.3 | 127.4 | .2635 | 3,100 | 32.24 | 2,985 | 41.08 | ...... | ...... | ...... | Dark sandy loam, level; season cold, but enough rain. |
| Lambert F. L., Charles City, Iowa. | 1911 | ([1]) | 180 | ([1]) | 180 | ...... | 100 | .0389 | ...... | 66.1 | ...... | 66.1 | ...... | ...... | ...... | Sandy loam, level; early part of season dry, later part wet. |
| Lemmon, R. H., Winnsboro, S. C. | 1911 | ([1]) | 66 | ([1]) | 54 | ...... | 81.8 | .0275 | ...... | 34.3 | ...... | 28.05 | ...... | ...... | ...... | Fine sandy soil, rolling land; season very dry. |
| McClenden, S. E., Calhoun, La. | 1911 | ...... | 149 | ...... | 140 | ...... | 93.9 | .0965 | ...... | 22.06 | ...... | 20.72 | ...... | ...... | ...... | Land almost level; good season, except dry in May. |
| McCulloch, Fred, Hartwick, Iowa. | 1911 | 306 | 232 | [2] 302 | 206 | 98.7 | 88.8 | .0231 | 13,220 | 143.1 | 13,050 | 127 | ...... | ...... | ...... | Heavy black loam, level; season very dry. |
| Perry, J. B., Clarks Falls, Conn. | 1911 | 278 | 182 | 198 | 156 | 71.2 | 85.7 | .0442 | 6,290 | 58.8 | 4,480 | 50.4 | ...... | ...... | ...... | Loam, gravelly subsoil, level; extremely dry season. |
| Prince, A. H., San Augustine, Tex. | 1911 | ([1]) | 216 | ([1]) | 216 | ...... | 100 | .1147 | ...... | 26.9 | ...... | 26.9 | ...... | ...... | ...... | Sandy loam, level; on top of hill; too wet to cultivate; then too dry. |
| Ransom, E. R., Blandville, Ky. | 1911 | 10 | 52 | [3] 10 | 48 | 100 | 92.3 | .0138 | 724 | 53.8 | 724 | 49.7 | ...... | ...... | ...... | Rich clay in garden, level; dry and hot in summer. |
| Rector, J. H., Cumberland Gap, Tenn. | 1911 | ...... | 840 | ([3]) | 710 | ...... | 84.5 | .1806 | ...... | 66.4 | ...... | 56.1 | ...... | ...... | ...... | Clay loam, level; season very dry. |
| Seymour, R. R., Henning, Ill. | 1911 | ...... | 460 | ...... | 380 | ...... | 82.6 | .1683 | ...... | 39.05 | ...... | 32.25 | ...... | ...... | ...... | Silt loam, level; May to August dry. |
| Smith, C. S., Nokesville, Va. | 1911 | [1] 61.5 | 70.5 | [1] 58 | 67 | 94.3 | 95 | .0301 | 2,040 | 33.41 | 1,925 | 31.75 | ...... | ...... | ...... | Clay, level; season very dry until July 20. |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| U. S. Plant Introduction Garden, Chico, Cal. | 1911 | 212 | 86 | [2] 181 | 74 | 85.3 | 86 | .0482 | 4,418 | 25.52 | 3,770 | 21.95 | ........ | ...... | ....... | Sandy loam, level; season dry. |
| Total | ...... | 7,191 | 10,897 | 6,763.5 | 10,129.5 | ....... | ....... | 3.5745 | 60,591 | 1,281.74 | 56,764 | 1,191.9 | ........ | ...... | ....... | |
| Average | ...... | 479.4 | 435.9 | 450.9 | 405.2 | 91.24 | 92.37 | .1429 | 4,039 | 51.27 | 3,784 | 47.67 | ........ | ...... | ....... | |

[1] No difference in time of ripening.
[2] Ripened earlier.
[3] Ripened a few days earlier.

## RÉSUMÉ OF THE CORN-CULTIVATION EXPERIMENTS.

Table IV presents a résumé of all the experiments. The yield of the uncultivated plat is expressed as a percentage of the yield of the cultivated plat. The average percentages shown in Tables I and III are here compiled for comparison. Of the total number of 125 tests whose data are recorded in this bulletin, 1 test shows fodder yields only, 54 tests show yields of both fodder and grain, and 70 tests show grain yields only. The data on grain yields are, therefore, given for 124 and on fodder yields for 55 of the total number of experiments. The general average for all the experiments shows that the fodder on the uncultivated plats was 95.1 per cent of the cultivated and that the uncultivated grain was 99.108 per cent of the cultivated.

TABLE IV.—*Résumé of average results of experiments in corn tillage.*

| Designation of experiments. | Fodder. | | Grain. | |
|---|---|---|---|---|
| | Number of experiments. | Average yield of uncultivated plats expressed as percentage of cultivated. | Number of experiments. | Average yield of uncultivated plats expressed as percentage of cultivated. |
| Early experiment station work (Table I) | 2 | 85.35 | 12 | 98.5 |
| 1905 and 1906 (Table III) | 3 | 96.36 | 5 | 108.4 |
| 1907 (Table III) | 2 | 91.6 | 8 | 110.84 |
| 1908 (Table III) | 4 | 94.95 | 6 | 97.93 |
| 1909 (Table III) | 10 | 101.15 | 25 | 105.27 |
| 1910 (Table III) | 19 | 96.19 | 43 | 96.51 |
| 1911 (Table III) | 15 | 91.24 | 25 | 92.37 |
| Total | 55 | | 124 | |
| General average | | 95.1 | | 99.108 |

## GEOGRAPHICAL DISTRIBUTION OF THE EXPERIMENTS.

Figure 8 shows the distribution of the experiments in the various States. It will be noted that the conditions of soil and climate under which the tests were made are quite varied. The total number of experiments recorded in the summary is 125 and the number of States represented in this work 28. In Table V the location of the experiments by States is correlated with the average yield of grain from the uncultivated plats expressed as a percentage of the average yield of grain from the cultivated plats.

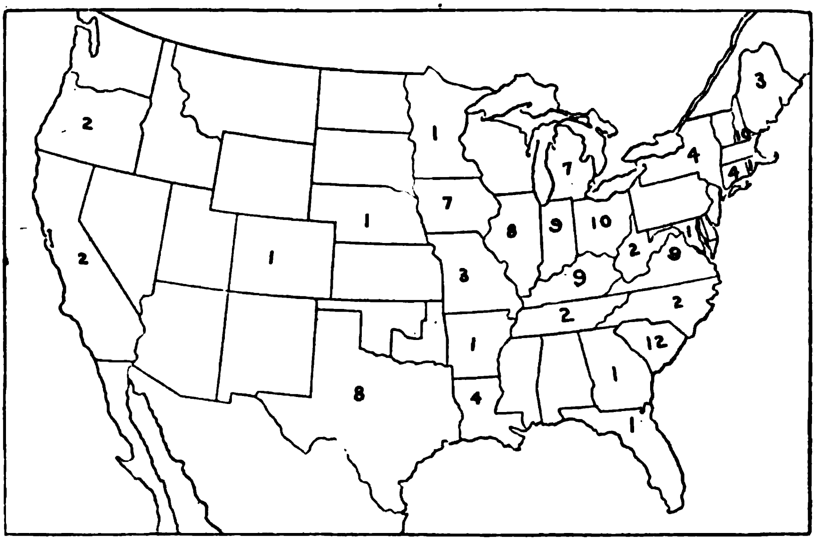

FIG. 8.—Map showing the distribution of the corn-cultivation experiments in the various States.

TABLE V.—*Relative grain yield by States.*

| State. | Number of experiments. | Average yield of uncultivated plats expressed as percentage of cultivated. | State. | Number of experiments. | Average yield of uncultivated plats expressed as percentage of cultivated. |
|---|---|---|---|---|---|
| Arkansas | 1 | 77.4 | Missouri | 3 | 103.2 |
| California | 2 | 86.8 | Nebraska | 1 | 101.9 |
| Colorado | 1 | 90.1 | New Hampshire | 10 | 112.71 |
| Connecticut | 4 | 98.8 | New York | 4 | 104.7 |
| Florida | 1 | 87.1 | North Carolina | 2 | 92.15 |
| Georgia | 1 | 138.8 | Ohio | 10 | 96.17 |
| Illinois | 8 | 94.74 | Oregon | 2 | 99.3 |
| Indiana | 9 | 105.36 | Rhode Island | 1 | 89.6 |
| Iowa | 7 | 102.72 | South Carolina | 12 | 99.07 |
| Kentucky | 9 | 91.28 | Tennessee | 2 | 89.4 |
| Louisiana | 4 | 105.8 | Texas | 8 | 92.59 |
| Maine | 3 | 77.9 | Virginia | 9 | 88.51 |
| Maryland | 1 | 109.2 | West Virginia | 2 | 77.9 |
| Michigan | 7 | 116.26 | | | |
| Minnesota | 1 | 100 | Total | 125 | |

## RELATIVE MATURITY OF CULTIVATED AND UNCULTIVATED CORN.

In 1909, 1910, and 1911 the cooperators were asked to report which of the two plats or sets of plats matured first. Note of this matter was made by 68 of them, 39 of whom reported no difference in the date of ripening, while 10 stated that the cultivated plats ripened first and 19 stated that the uncultivated plats were first to ripen. The average grain yield from the uncultivated plats expressed as a percentage of the yield from cultivated plats in these three groups is approximately 100 per cent for the first two groups and 95.58 per

cent for the third group. These results are shown in Table VI, and they seem to indicate that when for any reason the uncultivated plat falls below the cultivated plat in yield the uncultivated corn has a tendency to mature earlier than the cultivated corn.

TABLE VI.—*Relative time of maturity of cultivated and uncultivated corn.*

| Relative time of maturity. | Number of experiments. | | | | Average grain yield of uncultivated expressed as percentage of cultivated. |
|---|---|---|---|---|---|
| | 1909 | 1910 | 1911 | Total. | |
| Cultivated ripened first | 3 | 7 | 0 | 10 | 100.36 |
| No difference in time of ripening | 11 | 18 | 10 | 39 | 101.68 |
| Uncultivated ripened first | 3 | 9 | 7 | 19 | 95.58 |
| Total | 17 | 34 | 17 | 68 | |

## RELATION OF CORN-TILLAGE RESULTS TO RAINFALL.

In the annual charts of the experiments, with the exception of the year 1911, for which the data are not yet available, are given the actual rainfall, the mean rainfall, and the actual rainfall expressed as a percentage of the mean. As previously stated, this rainfall is for the last three months of the previous year and for the first nine months of the year in which the experiment was conducted. Rainfall data are available for 95 of the 124 experiments. Of the whole series of experiments the lowest rainfall with reference to mean was 42 per cent and the highest 133 per cent. In two experiments a rainfall of over 120 per cent of the mean was recorded, while in three experiments the rainfall was less than 60 per cent of the mean. Working out the relation between the yield of the uncultivated plats expressed in percentage of the yield of the cultivated plats and the rainfall expressed in terms of percentage of the mean rainfall, there was found to be a correlation of only $0.142 \pm 0.065$, which can not be considered significant.

In actual rainfall the lowest precipitation for any experiment was 16 inches for the year and the highest 61 inches. The greater number of the experiments upon which rainfall data are presented received from 30 to 40 inches of rain for the period. Working out the correlation between the yield of the uncultivated plat, expressed in percentage of the cultivated, and the actual rainfall, there was found to be a correlation of only $0.0188 \pm 0.067$.

These data do not indicate that rainfall enters into the problem to any appreciable extent

## RELATION OF CORN-TILLAGE RESULTS TO SOIL PRODUCTIVITY.

The results of all the tillage experiments were studied with the object of determining whether the factors which influence grain yield had any effect on the yield of uncultivated corn as compared with the cultivated. For this purpose the experiments were considered in three groups: Group 1, containing those experiments in which the yield on the cultivated plats fell below 30 bushels per acre; group 2, those varying from 25 to 60 bushels; and group 3, those above 50 bushels. By thus overlapping the limits of the various groups it was thought that tendencies would be shown more clearly than if absolute limits were observed.

Little evidence is shown that any relation exists between these two factors. Group 1, containing the lowest grain yields, shows the average yield on the uncultivated plats to be 97.19 per cent of that on the cultivated; group 2 shows 99.59 per cent; and group 3 shows 98.34 per cent. The details are given in Table VII.

TABLE VII.—*Relation of corn-tillage results to soil productivity.*

| Year. | Experimenter. | Yield of cultivated plat per acre. | Yield of uncultivated plat expressed as percentage of cultivated. |
|---|---|---|---|
| | GROUP 1.—*Yields less than 30 bushels per acre.* | | |
| 1906.. | New Hampshire experiment station | *Bushels.* 23.3 | 141.6 |
| 1908.. | North Carolina experiment station | 11.55 | 92 |
| 1909.. | Callison, N. A | 25.3 | 87.1 |
| | Campbell, J. M | 12.2 | 66.8 |
| | Cunningham, T. J | 22.5 | 115 |
| | Foster, W. L | 16.6 | 114.7 |
| | Rich, E. A. J | 26.7 | 138.8 |
| | Seay, Robert | 29.7 | 80.6 |
| | Sugar Experiment Station | 20.6 | 100 |
| | Wollschlaeger, Gus | 19.2 | 101.7 |
| 1910.. | Campbell, J. M | 24 | 107.1 |
| | Crum, H. C | 21 | 114.3 |
| | Ferguson, A. M | 5.67 | 95.9 |
| | Gardner, E. T | 16.2 | 90.1 |
| | Howle, P. L | 15 | 97.1 |
| | Marvin, Jas. A | 23.9 | 104.2 |
| | McClelland, C. K | 10.37 | 77.4 |
| | U. S. Plant Introduction Garden | 12.4 | 87.6 |
| | Wollschlaeger, Gus | 23.78 | 99.3 |
| 1911.. | Hester, H. C | 7.1 | 53.3 |
| | Hill, L. E | 11.26 | 88 |
| | McClendon, S. E | 22.06 | 93.9 |
| | Prince, A. H | 26.9 | 100 |
| | U. S. Plant Introduction Garden | 25.52 | 86 |
| | Average | | 97.19 |
| | GROUP 2.—*Yields between 25 and 60 bushels per acre.* | | |
| 1886.. | New York experiment station (Geneva) | *Bushels.* 56.8 | 124.1 |
| 1890.. | Missouri experiment station | 54 | 84.6 |
| 1891.. | Illinois experiment station | 58.4 | 94.7 |
| 1893.. | do | 36.3 | 79 |
| 1898.. | South Carolina experiment station | 58.6 | 96.4 |
| 1906.. | Purdue experiment station | 46.97 | 95.9 |
| 1907.. | Cornell experiment station | 50.3 | 103.4 |
| 1908.. | Arlington Experimental Farm | 41.4 | 97.7 |
| 1909.. | Anderson, W. B | 48.1 | 136.5 |
| | Barrett, J. M | 52.2 | 123.7 |
| | Arlington Experimental Farm | 30.6 | 74.1 |
| | Callison, N. A | 25.3 | 87.1 |
| | Lambert, F. L | 56.4 | 115.3 |
| | Leffler, G. V | 40.5 | 109.6 |
| | Perry, J. B | 45.7 | 108.7 |
| | Purdue experiment station | 42 | 100.25 |
| | Rich, E. A. J | 26.7 | 138.8 |
| | Seay, Robert | 29.7 | 80.6 |
| | Tenney, W. P | 31.25 | 170.5 |
| 1910.. | Bigstaff, T. J | 37.65 | 96.6 |
| | Day, A. P | 47.9 | 87 |
| | Finley, W. W | 48.8 | 92.3 |
| | Fredericks, C. P | 50.14 | 106.4 |

TABLE VII.—*Relation of corn-tillage results to soil productivity*—Continued.

| Year. | Experimenter. | Yield of cultivated plat per acre. | Yield of uncultivated plat expressed as percentage of cultivated. |
|---|---|---|---|
| | GROUP 2.—*Yields between 25 and 60 bushels per acre*—Cont'd. | | |
| | | *Bushels.* | |
| 1910.. | George, H. C. | 55.4 | 90 |
| | Heuser, W. L. | 48.9 | 82.4 |
| | Huyett, J. B. | 33.1 | 69.7 |
| | Kirkpatrick, L. R. | 38 | 68.4 |
| | Lambert, F. L. | 55 | 100 |
| | Lemmon, R. H. | 47.9 | 100 |
| | Perry, J. B. | 42.45 | 100.9 |
| | Ratliff, W. S. | 42 | 123.9 |
| | Ross, Henry | 30.9 | 99 |
| | Royce, Oscar | 49.65 | 111.2 |
| | Sugar Experiment Station | 30.5 | 114.7 |
| 1911.. | Brant, W. C. | 33.5 | 104.4 |
| | Dailey, S. C. | 38.5 | 93.3 |
| | Day, A. P. | 54.3 | 68.8 |
| | Heuser, W. L. | 39.7 | 113.9 |
| | Huyett, J. B. | 57.7 | 86.1 |
| | Ladd, E. O. | 32.24 | 127.4 |
| | Lemmon, R. H. | 34.3 | 81.8 |
| | Perry, J. B. | 58.8 | 85.7 |
| | Prince, A. H. | 26.9 | 100 |
| | Ransom, E. R. | 53.8 | 92.3 |
| | Seymour, R. R. | 39.05 | 82.6 |
| | Smith, C. S. | 33.41 | 95 |
| | U. S. Plant Introduction Garden | 25.52 | 86 |
| | Average | | 99.59 |
| | GROUP 3.—*Yields more than 50 bushels per acre.* | | |
| 1886.. | New York experiment station (Geneva) | 56.8 | 124.1 |
| 1888.. | Illinois experiment station | 93.8 | 95.9 |
| 1889.. | do | 84.6 | 91.1 |
| 1890.. | do | 66.8 | 103.4 |
| 1891.. | do | 58.4 | 94.7 |
| 1892.. | do | 70.1 | 109.5 |
| 1896.. | do | 85.5 | 101.7 |
| 1889.. | Missouri experiment station | 80.1 | 101.3 |
| 1890.. | do | 54 | 84.6 |
| 1898.. | South Carolina experiment station | 58.6 | 96.4 |
| 1899.. | do | 67.3 | 100.3 |
| 1907.. | Cornell experiment station | 50.3 | 103.4 |
| | Froley, J. W. | 65.3 | 109.2 |
| | Nebraska experiment station | 61.9 | 101.9 |
| | Purdue experiment station | 77 | 108.7 |
| | GROUP 3.—*Yields more than 50 bushels per acre*—Cont'd. | | |
| | | *Bushels.* | |
| 1908 | Minnesota experiment station | 62.5 | 100 |
| | New Hampshire experiment station | 67.9 | 100.4 |
| | Purdue experiment station | 62.5 | 96 |
| 1909 | Barrett, J. M. | 52.2 | 123.7 |
| | Dimond, O. C. | 62.4 | 121.1 |
| | Lambert, F. L. | 56.4 | 115.3 |
| | Lee, J. J. | 81.3 | 96 |
| | Littlejohn, W. D. | 73.8 | 95.3 |
| | McCune, Kate B. | 107.4 | 106.3 |
| | Merwin, G. H. | 78.4 | 100 |
| | Sawyer, R. S. | 71.3 | 69.1 |
| | Wallace, M. | 84.9 | 91.9 |
| | Watson, A. D. | 67.4 | 99.1 |
| | Welch, E. K. | 64.2 | 109.7 |
| 1910 | Anderson, W. B. | 62.6 | 99.2 |
| | Brant, W. C. | 70.3 | 95.5 |
| | Case, J. H. | 65 | 107.7 |
| | Dailey, S. C. | 88.1 | 89.2 |
| | Dimond, O. C. | 90.6 | 90.9 |
| | Elmer, E. O. | 85.6 | 101.8 |
| | Fredericks, C. P. | 50.14 | 106.4 |
| | George, H. C. | 55.4 | 90 |
| | Goddard, W. R. | 84.9 | 93.3 |
| | Hansbarger, D. | 105.4 | 99.4 |
| | Hester, H. C. | 74.1 | 84 |
| | Lambert, F. L. | 55 | 100 |
| | Lloyd, F. L. | 63.5 | 101.6 |
| | McCune, Kate B. | 65.2 | 92.3 |
| | Morgan, Geoffrey | 98.1 | 116.3 |
| | Rector, J. H. | 139.7 | 94.3 |
| | Rinehart, N. W. | 104.6 | 84.2 |
| | Welch, E. K. | 70.5 | 126.2 |
| | Williams, D. W. | 106.2 | 100.8 |
| | Winsor, B. E. | 72.9 | 89.6 |
| 1911 | Anderson, W. B. | 74.3 | 97.5 |
| | Arlington Experimental Farm | 78.4 | 73.9 |
| | Day, A. P. | 54.3 | 68.8 |
| | Dimond, O. C. | 65 | 98.5 |
| | Elmer, E. O. | 63.6 | 106.4 |
| | Goddard, W. R. | 65 | 106 |
| | Housekeeper, G. C. | 91.7 | 99.1 |
| | Huyett, J. B. | 57.7 | 86.1 |
| | Lambert, F. L. | 66.1 | 100 |
| | McCulloch, Fred | 143.1 | 88.8 |
| | Perry, J. B. | 58.8 | 85.7 |
| | Ransom, E. R. | 53.8 | 92.3 |
| | Rector, J. H. | 66.4 | 84.5 |
| | Average | | 98.34 |

## SIMPLIFICATION OF WEED CONTROL WHEN THE SOIL IS NOT STIRRED.

A very interesting observation made during these investigations is that with some of the experiments on certain soils weeds ceased growing on the uncultivated plats sooner than on the cultivated ones, where the number of hoeings and cultivations, respectively,

was the same; so that at harvest time the uncultivated plats were quite free from weed growth and the cultivated plats were more or less weedy. An example of this is shown in figure 9, which illustrates a carefully conducted experiment on a rather stiff clay soil at the Arlington Experimental Farm. On the uncultivated plats of this experiment the weeds started growing immediately after planting to about the same extent as on the cultivated plats. But as the season progressed and the weed seeds in the surface inch or two of soil germinated and the seedlings were destroyed, the weed growth became gradually less, while on the cultivated plats the weeds continued to grow thriftily throughout the season. This tendency was shown in a number of experiments on soils of this kind. The reason for this may

FIG. 9.—Two plats at the Arlington Experimental Farm, the cultivated at the left and the uncultivated at the right, showing the difference in weed growth under the two methods of treatment.

be due to the condition of the soil on the uncultivated plats discouraging germination of weed seeds beneath the surface inch or two and the inability of the seedlings to push up through the hard crust, whereas on the cultivated plats the friable surface soil permitted the seedlings to push up from a considerable depth and the tillage implements were constantly bringing up weed seeds into the surface soil where conditions were more conducive to germination.

It was observed that on other soils, however, especially those of a loose, deep, moist character, the weed growth on the two sets of plats was about the same throughout the season.

Whether or not it is desirable to discourage the germination of weed seeds can not be stated definitely at the present time. It may be

argued on the one hand that the crop should be so tilled as to induce the germination of as many of the weed seeds as possible, with the subsequent destruction of the seedlings. On the other hand it may be argued that under the conditions that existed on the nontilled plats of these experiments, although a much smaller proportion of weed seeds in the soil was induced to germinate, many of those that remained ungerminated probably lost their viability and that as there was a much smaller number of weeds on these plats than where the land was tilled a correspondingly less number of weed seeds matured to reseed the land in the latter part of the season after cultivation stopped.

It must be understood that there are no data to prove which of the two opinions stated above is the correct one. It is impossible to say, therefore, which of the two methods of treatment would be the less conducive to weediness of the soil through a period of years during which different crops were grown. The observations on these experiments, however, seem to indicate that for the years in which the land is in cultivated crops the work of weed control may be considerably simplified by shallow rather than deep working of the soil.

## FAIRNESS OF THE TESTS.

Although the weed growth seemed to be less on the uncultivated plats than on the cultivated ones in some of the experiments, there were others where the surface scrapings or hoeings were not sufficient to keep down the weeds as thoroughly on the uncultivated plats as on the cultivated ones. It is believed, therefore, that on an average for all experiments the weed growth under the two kinds of treatment was about the same in extent, but that if there was any difference in this regard there were more weeds on the uncultivated than on the cultivated plats—due to the fact that some of the cooperators did not do as thorough work in keeping down weeds on the uncultivated plats as on the cultivated ones.

Another point which may have affected the fairness of the tests was that where the experiments were located on sloping land there was a tendency for rain water (especially at times of heavy rains) to run off the uncultivated plats to the adjoining cultivated ones, where it was caught and allowed to soak in the soil, on account of the rough and absorptive condition of its surface, so that the cultivated plats received more than their share of the precipitation.

Altogether, if there was any advantage in favor of either of the sets of plats it was on the side of the cultivated ones.

RELATION OF TESTS SHOWN BY FREQUENCY CURVE.

The frequency curve (fig. 10) shows that the results secured are not of a mere haphazard nature. Of the total number of experiments 46 per cent give results between 92.5 and 107.5 per cent of uncultivated grain in terms of the cultivated. These limits come well within the bounds of experimental error. The general average,

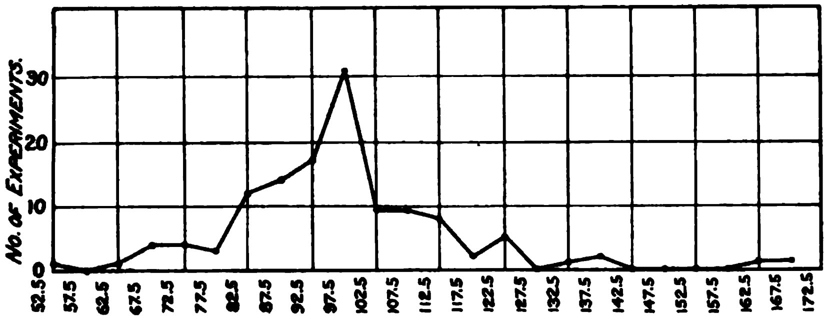


FIG. 10.—Diagram showing the yields of uncultivated plats of corn expressed in percentages of yields of cultivated plats for 124 experiments in 28 States.

therefore, of the whole 124 tests, showing 99.108 per cent as much grain produced on the weeded plats as on cultivated plats, is significant.

INTERPRETATION OF THE RESULTS OBTAINED.

The reasons why uncultivated land kept free from weeds should yield practically as much corn (grain) per acre as that given the most approved modern cultivation are not clear. The results, however, point strongly to the conclusion that the principal object of cultivation is the destruction of weeds. Where the weeds are kept down by some other method cultivation seems to be of no particular advantage. This is contrary to the accepted teaching on this point, and the conclusion is stated only tentatively. There have been abundant experimental results to show that when land is fallow a soil mulch upon it tends to preserve the moisture in the soil. It appears quite possible that when the soil is fully occupied by the roots of a growing crop there is little possibility of moisture from the deeper layers of the soil being drawn by capillary action to the surface, where it could be evaporated, for in doing so the moisture would have to thread its way through a maze of roots eager to absorb it. Does it not seem that these roots would themselves play the part that a soil mulch would play if the roots were not there? If such is the case, what additional advantage would arise by having a mulch

on a surface beneath which is a tangle of fine roots capable of absorbing any moisture that might try to pass upward to the surface?

On the other hand, these roots would not interfere to any great extent with the progress of rain water downward in the soil, for when rainfall is great enough to saturate the surface soil there would be more moisture present than the roots could absorb. Thus, while the soil mulch is important on fallow soils as a means of holding moisture, is it not possible that a soil well filled with living plant roots is not in need of a mulch for this purpose? This would at least be a plausible explanation of the results reported in this bulletin.

It is further suggested that these results may partly be due to the fact that tillage mutilates the surface roots of the crop. Again, a fall of rain too light to moisten the soil below the depth of stirring would all be lost on the cultivated land because it would not reach the roots of the crop, while on the weeded plat there would be enough roots in the surface soil to absorb a considerable proportion of such light rainfall before it had time to evaporate.

While the suggestion that the presence of a maze of living roots in the soil would itself, to a large extent, prevent loss of moisture by evaporation at the surface, it is not proved that this is the case. We must therefore consider other possibilities. Even with ordinary methods of cultivation there would be some loss of moisture at the surface, for tillage itself would expose a large amount of moist soil to the atmosphere, so that in any case a growing crop would hardly utilize all the rainfall that occurs during a growing season. If, however, the loss of moisture by evaporation is greater on the uncultivated plats than on the cultivated ones it is possible that this would be compensated for by a correspondingly greater amount of nitrates and other soluble salts being brought up from the deeper layers of the soil to the surface, thus furnishing a greater quantity of plant food for the corn roots.

It should be clearly understood that the writers offer these remarks merely as suggestions. The underlying causes for the phenomena observed must be left for future determination.

## PRACTICAL SIGNIFICANCE OF THE RESULTS.

An explanation of the results obtained in these experiments is of secondary importance as compared with the interpretation we shall give them from a practical standpoint. The results as a whole come well within the limits of experimental error, showing no more difference in yield between the weeded plats and those receiving normal cultivation than might be expected between two series of 125 plats treated exactly alike.

Table V shows the results of the experiments by States. As only a small number of experiments have been conducted in some States, it is probable that another set of tests would show considerable difference in results in many localities. It would not be advisable, therefore, to make practical suggestions for any particular locality based on the indications of these results as a whole without first making actual tests to see whether under local conditions these same principles will govern. Where these results are found to hold good, however, two entirely new fields of research are opened up, and their practical importance to the corn growers of America from a labor and money saving standpoint is not to be gainsaid.

If it be true that weeds make the cultivation of corn necessary the problem immediately presents itself as to what farm-management methods can be pursued to eliminate or reduce to a minimum the weed pests of the farm. In this connection we have (1) the problem of what may be termed persistent perennial weeds. Among this group may be mentioned Johnson grass, quack-grass, Bermuda grass, wild morning-glory, Canada thistle, wild onion, and horse nettle. Publications already issued by the Department of Agriculture deal with the control of these pests. In the main these weeds require special treatment to eradicate them. We have (2) the biennial and annual weeds, which are troublesome largely through their prolific seed habits. As a class these weeds should be prevented from going to seed until all the seeds infesting the land shall have germinated and the seedlings have been destroyed.

Our present implements for cultivation are designed primarily to produce a mulch and stir the ground. Weed killing is a secondary function. It is possible that newly designed implements made with special reference to weed control could accomplish this end with greatly decreased cost. The weeder will probably be considered of vastly more importance than heretofore when more data with reference to its use are available.

Another large field of investigation in connection with weed control is of much practical importance to the farmer. This field of work might be outlined as a study of those systems of farming or rotations which are especially calculated to lessen the weed pests on the farm. It is a well-known fact that certain rotations of crops bring us round to the tillage crop with the land practically free from weed pests. One experiment is reported where a piece of sod land very free from everything but clover and timothy was put to corn and no cultivation given, as no weeds were present; a crop of 70 bushels per acre was produced. In some sections of the South, where a 1-year rotation of corn and crimson clover is practiced, the weeds are reduced to a minimum and many farmers cultivate corn on such

land only once and secure large yields. Studies are being conducted on this problem of adapting cropping systems to weed control, and more data will be at hand at a later date.

Just what implements are best to destroy weeds when present and just what rotations should be practiced to control them are largely local problems. Each State or agricultural region will have its own answer. In those cases where a soil mulch may be desirable it will undoubtedly be true that any tillage implements designed primarily to kill weeds will incidentally produce a sufficient soil mulch to answer all requirements in this respect.

The writers interpret the results here presented to mean that weeds are in the main the enemy which makes cultivation necessary. The exceptions should be determined by further work. Weeds can be fought from two standpoints: (1) With tillage implements specially designed to kill these pests instead of to stir the soil and make a mulch and (2) from the standpoint of rotations especially designed to overcome the weeds of the particular locality. It is believed that by adopting methods in conformity with this point of view the weed problem will be simplified and in all probability the cost of cultivation will at the same time be greatly decreased.

## SUMMARY.

A number of tests made at several agricultural experiment stations seem to indicate that it is the weed factor that makes the cultivation of corn necessary, or, stating the proposition conversely, that cultivation is not beneficial to the corn plant except in so far as removing the weeds is concerned.

The subject of weed control is recognized as a fundamental one in tillage philosophy. It was therefore determined to carry on, over a wide range of climatic and soil conditions, a large number of tests of the relative yields of corn produced by supposedly optimum cultivation as compared with mere weed elimination.

The experiments were made by having two plats or sets of plats, one of which received no cultivation after planting, the weeds being kept down by a horizontal stroke of a sharp hoe at the surface of the soil, particular care being taken not to disturb the soil or to form a soil mulch; the other set of plats received the usual cultivation.

This work was carried on by the Department of Agriculture for six years (1906 to 1911) in cooperation with several State agricultural experiment stations and with farmers, many of whom were graduates of agricultural colleges. The results of 125 experiments are recorded in this bulletin, including the early experiment-station tests. The seven years' work in Utah is given separate discussion. Of the 125 experiments 124 record grain yields and 55 give fodder yields.

A general average of all of these experiments shows that the weeded plats produced 95.1 per cent as much fodder and 99.108 per cent as much grain as the cultivated ones. If there was any difference between either set of plats in regard to thoroughness in keeping down weeds it was in favor of the cultivated plats.

Although it remains to be demonstrated how far this principle may be applied in any particular section, as a general average for all the regions in which this work was done it may be concluded that the proposition just stated is substantially true. If this be accepted, weed control becomes the principal object of cultivation.

Weeds may be attacked in two ways: (1) By the use of tillage implements, the primary purpose of which is their eradication, and (2) by adopting cropping systems having that object in view.



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BUREAU OF PLANT INDUSTRY—BULLETIN NO. 258.

B. T. GALLOWAY, *Chief of Bureau.*

# SOME NEW ALFALFA VARIETIES FOR PASTURES.

BY

GEORGE W. OLIVER, *Plant Breeder and Propagator.*

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1913.

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## LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Plant Industry,
Office of the Chief,
*Washington, D. C., June 1, 1912.*

Sir: I have the honor to transmit herewith a manuscript entitled "Some New Alfalfa Varieties for Pastures," by Mr. George W. Oliver, Plant Breeder and Propagator, and recommend that it be published as Bulletin No. 258 of the series of this bureau.

Respectfully,

B. T. Galloway,
*Chief of Bureau.*

Hon. James Wilson,
*Secretary of Agriculture.*

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# ILLUSTRATIONS.

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# SOME NEW ALFALFA VARIETIES FOR PASTURES.

## INTRODUCTION.

The lines of investigation worked out in this paper were briefly outlined to the writer a few years ago by Dr. B. T. Galloway. The material experimented with includes numerous plants of the Grimm, Turkestan, Baltic, and Mongolian alfalfas, obtained from many sources, including the strains raised by Prof. W. A. Wheeler, of South Dakota, and the selections of hardy plants made by Mr. John M. Westgate and Mr. Charles J. Brand, of the Bureau of Plant Industry. The valuable collections obtained in foreign countries by Mr. Frank N. Meyer, one of the agricultural explorers of the Bureau of Plant Industry, and the plants selected abroad by Prof. N. E. Hansen, of the South Dakota State College of Agriculture, have all been utilized in breeding new races of alfalfa.

The first work undertaken with the large amount of material available was to become familiar with the characters peculiar to each of the widely different groups. During the progress of this investigation important characters were found which in the different groups seem correlated with hardiness and drought resistance. These characters consist of the underground development of rhizomes and modified rhizomes.

In the numerous crosses which have been made at the Department of Agriculture during the last three summers much attention has been given to these underground characters, because the alfalfa which has a root system that assures hundreds of resting buds, in some cases no less than 12 inches below the surface of the soil, is the variety which may be expected to withstand semiarctic conditions. Other plants with very large succulent rhizomes several feet in length evidently function during protracted dry spells partly through their storage of water.

A large number of crosses have been developed, in most cases only to the first generation. Many of the plants have been fruited and seedlings of the second generation raised. The principal object in

making these crosses is not so much the improvement of the strains now growing in this country as it is to provide strains adapted to pasturage which will succeed in the large areas where alfalfa is not grown at all.

In so far as the project has progressed, the outcome is highly promising. The Department of Agriculture, however, has as yet nothing to distribute and will not have until the crosses are an assured success in the areas referred to.

During the study of perhaps the largest number of what are considered distinct species and forms ever brought together in a single collection, it becomes evident that until recently very little has been ascertained concerning the life history of the alfalfas of the world. They are a much mixed lot of plants, as scarcely any of them, even when gathered in localities where they seem to be native, come invariably true from seed. This unfortunate condition is due to the cross-pollination of the flowers by insects, but it is possible to breed them to come true to type, and the result is worth the effort necessary to accomplish it.

During the progress of the initial stages of breeding alfalfa for different sections of the country it became evident that the extensive rhizome development of some of the wild forms, so far as the writer has been able to ascertain, has never been taken into consideration in hybridizing work to perfect hardy and drought-resistant strains.

The hybrid combinations are startling in their abundant growth, both above and below ground. This bulletin has been written partly to call attention to these characters and partly to place on record a number of crosses already made.

## PROVISION FOR THE PERPETUATION OF TYPES IN ALFALFAS COMPARED WITH COWPEAS.

In the first generation of a cross between two varieties of the cowpea each plant is like its neighbor, and no difference can be detected in, say, 12 plants, which number is frequently secured in a single cross. The habit of growth, color, size, and shape of pod and the color, size, and shape of seeds are in each case alike. The flowers of the parents are self-pollinating and the plants of a fixed variety come true from seed, because each stigma is pollinated with the pollen of its own flower. When, however, the flowers of two plants are crossed and these two plants are dissimilar in many or few characters, such as spreading and upright habits, and the seeds are different in their markings, one, for instance, being white with a black eye and the other speckled like the Whippoorwill variety, the progeny in this first generation will have black seeds. In the second generation the color combinations, also the size and form of seed, are numerous;

sometimes in as many as 16 series of plants observed the seeds of any one series are entirely unlike those of the other 15. In the next sowing the seeds of each plant of the second generation are sown separately and only those in this, the third, generation which resemble those of the second are again saved. If they continue to come true in the next, or the fourth, generation, they will always come true.

With alfalfas, however, a very different problem is presented, in that very often the parents selected do not come true even from seeds resulting from flowers which have been self-pollinated. The reason for this is that the flowers are perfectly constructed for intercrossing. A seed parent selected for crossing sometimes gives over a dozen distinct forms when inbred. All of these when inbred again do not come true, but occasionally a plant will be found which has the characters of the original plant. This absolutely essential preparation for crossing requires at least two seasons before one can be reasonably certain that he has parents which are fixed enough in the desired characters to begin hybridizing.

## THE ALFALFAS OF NORTHERN AFRICA.

Dr. B. T. Galloway, while abroad last year, discovered a large number of alfalfas in flower, many of which looked promising, none of which he had seen in the United States. Later in the summer, seeds of all these plants were collected by the writer, chiefly in northern Africa. Most of them were found in abandoned patches of exceedingly poor soil at one time cultivated by Arabs. The manner of their occurrence suggests that they are introduced rather than native species. Whatever their origin, more species and forms of alfalfa occur in northern Africa than have been reported in any other region of the world.

Most of these forms have never been tried on American farms. Some of the plants from which seeds were imported are puzzles in a botanical classification. Among the number there are tall, strictly upright forms with glutinous hairs and large yellow flowers which perhaps belong to the form known as *Medicago sativa glutinosa*. Others of this class have bluish green flowers, between those of *M. sativa glutinosa* and *M. sativa glandulosa*. Some again have falcate pods studded with glandular hairs, probably crosses between *M. falcata* and *M. sativa glutinosa*. Some plants of exceedingly upright growth and showing every indication of being typical *M. sativa* had the telltale glandular pubescence on the pods. Some of these plants have more seeds to the individual than any hitherto recorded. Seedlings from all these plants, including 49 forms, are now growing at Washington and they will be used shortly on a small scale for testing, so that a study can be made of them as a basis for future hydridizing.

A plant which seems to be nearest *Medicago sativa gaetula* was found a few miles west of Algiers. This plant has longer rhizomes than any other wild alfalfa received by the Department of Agriculture. Some rhizomes developed on a specimen brought to Washington which are over 3 feet 6 inches in length. (Pl. I, fig. 1.) One plant observed covered an area of fully 9 square feet. The rooted growths of the previous season were easily traced to the mother plant, which was evidently little more than a 1-year-old seedling. In the case of older plants it was difficult to disentangle the rhizome growths. This plant has purplish yellow flowers and glandular hairy pods. Its nature seems to fit it for growth in arid regions, especially in sandy soils or in those not liable to become hard. There is a possibility that this plant may be found to endure considerable cold, as the rhizomes are very deep in the soil.

### WILD RHIZOME-FORMING ALFALFAS.

Mr. Frank N. Meyer has been very successful in securing seeds and plants of rare alfalfas, some of which show rhizome development far in excess of any of our cultivated forms, with the exception of *Medicago sativa gaetula*. These alfalfas include forms of *M. falcata* which, together with the forms secured by Prof. Hansen, show a variation in height from a few inches to 5 feet 8 inches. These plants vary widely in their underground characters, in that some from very cold regions have exceedingly long taproots which evidently do not branch until they are several feet in the ground. A plant of this nature obtained by Mr. Meyer in Siberia is seen in Plate II, figure 1. Another very hardy form does not produce a taproot, but has a branching type of root. This is S. P. I. No. 20721.[1] Plants of *M. falcata* found in the Caucasus and Crimean regions, which are said to be protected during the winter by a deep covering of snow, show absolutely no signs of taproots, but their long rhizomes are well developed and produce roots along their entire length. (Pl. XI, fig. 2.) Late in the fall the tips of these rhizomes come to the surface or near it. Those which have small leaves above the surface do not seem to suffer in the least when exposed without any covering to a temperature of −13° F.

All these plants have been used in crossing with diverse strains, such as the Grimms, Turkestans, and others. The dwarf *Medicago falcata* has been crossed with a taller growing rhizome-bearing form of the same species. The winter condition of this hybrid is seen in

[1] The letters "S. P. I." stand for "Seed and Plant Introduction," and the numbers refer to the series of plants and seeds brought into the United States by the Office of Foreign Seed and Plant Introduction of the Bureau of Plant Industry.

Plate III, figure 1. The rhizomes go down in the ground to a depth of over 12 inches. (Pl. III, fig. 2.)

There are exceedingly dissimilar types of *M. falcata*, all of which for want of descriptive specific and varietal names must be classed under a single name. The plant to which Linnæus gave the name *falcata* was a prostrate form, but to what extent it was prostrate will perhaps never be known, as herbarium specimens of prostrate forms might be easily mistaken for decumbent ones.

Between the two extremes in height mentioned, forms characterized by other differences are found, such as semiprostrate and decumbent forms, some with hairy pods perfectly straight, others sickle shaped, some with smooth pods, some black, others brown, and some of them even with glandular pubescence. In the foliage there are quite as many variations; broad, narrow, flabby, hard, dark green to bluish green, some with a great profusion of flowers, others with but few, and all of them shy seeders, possibly on account of a seemingly meager supply of pollen grains. The pods of most of them shatter badly, but Mr. Meyer has found a strain in Siberia which does not shatter.

## NEW RHIZOME-FORMING ALFALFA HYBRIDS.

Among the numerous consignments consisting of several species and varieties of alfalfa received in recent years by the Office of Foreign Seed and Plant Introduction a few of the plants gave decided promise as parents of new strains for pasturage purposes.

These alfalfas have been under observation for three seasons. They are natives of the Crimea and the Caucasus. Their principal claim to attention is their ability to bury the resting buds of the rhizomes several inches under the soil, which not only insures a crop of branches for the following season by reason of considerable protection from low temperatures, but also prevents the destruction of the plants by browsing animals. Among the new plants there is considerable diversity in habit of growth. Some of them are quite prostrate, never attaining a height over 6 inches. Some of these, however, give a fairly large quantity of forage, but on account of their prostrate natures can not very well be converted into dry fodder. Some of the forms have bluish purple flowers and very small, dark-colored, twisted pods. Other forms are between the last-named and the semi-upright forms of *Medicago falcata*. None of them is of strictly upright growth to such an extent that it could be harvested by ordinary methods. Even in their present condition, some of these prostrate forms are fairly well adapted to grazing purposes and in this capacity they would probably excel all

other low-growing legumes. However, there are some which are quite prostrate and which do not have rooting rhizomes and some which are without rhizomes of any description.

During the summer of 1910 the best of these prostrate plants, which were well provided with deeply set rhizomes, were crossed with forms of *Medicago falcata*, which also showed good rhizome development but almost prostrate growth above ground. These hybrid strains are being developed for the several areas where ordinary alfalfa does not succeed. Plate III, figure 1, gives a fair idea of their ability to withstand extremes of drought and cold. During the summer the plants were repeatedly cut over at a point 1 inch below the surface of the soil. When finally they were allowed to grow they made a more rampant growth than those plants which were left uncut. (Pl. IV, fig. 1.)

In order to obtain moderately large quantities of seeds quickly vegetative propagation will have to be resorted to. One man can place in sand enough cuttings in one day to plant a quarter of an acre in rows 3 feet apart, the plants 18 inches apart in the rows. The cuttings are easily manipulated. It is only necessary to cut them with a sharp knife, each cutting to be 3 to 5 inches long, according to the variety and the condition of growth, remove the lower leaves, and set in sand. When kept cool, moist, and protected from sunshine they root within three weeks. They are then placed in flats of soil; within 10 days strong roots are formed. (Pl. V, fig. 1.) After a rain they are transferred to permanent quarters in the field. The plants will, in a measure, take care of themselves. If any large overshadowing weeds make their appearance they should be cut down until the young alfalfa plants have ripened a crop of seed. Plate III, figure 1, shows a plant from an 8-inch pot. The cutting from which this plant grew was rooted in May, 1911, and the photograph was taken in October of the same year.

These new rhizome-forming alfalfas will probably succeed best in the Northwestern and Eastern States having limestone soils. They do not succeed so well in heavy soils as they do in soils having a considerable proportion of sand. There is also a possibility that some of the hybrid forms will thrive in the semiarid regions of the country.

## DEVELOPMENT OF ROOTING RHIZOMES OF PASTURAGE ALFALFA HYBRIDS.

It is exceedingly interesting to watch the development of the rooting rhizomes on the artificial hybrids. Sometimes rhizomes develop on the seedlings when only a few weeks old. A good example is a young plant of cross No. 284 (see Pl. X, fig. 2), which

has as its parents Grimm, F. C. I.[1] ♂ No. 138 ♀ × S. P. I. No. 28042. The latter is thought to be a form of *Medicago sativa gaetula*. A mature plant of this cross is seen in Plate VI. The seedling mentioned has the rhizomes attached to the root fully 3 inches below the bases of the lowest buds, which are situated immediately above the cotyledon scars. Cases of this nature must be somewhat rare, as they have been found by the writer only in this cross.

Other plants of this cross, examined eight months after they were planted out, show the point of attachment of the rhizomes to be the basal portions of the original branches from the axils of the cotyledons. These rhizomes begin their growth within two months after germination. (Pl. VII, fig. 1.) By the end of September several growths above ground were formed at a distance of 10 inches from the main crown, and from the bases of these growths a large crop of rhizomes are again formed before the advent of cold weather. (Pl. VI.) Many of the individuals of the crosses, especially those in which the Peruvian alfalfa has been crossed with a plant having very long underground rooting rhizomes, show a condition the significance of which can not be predicted with certainty. The growth above ground is strictly upright. The dormant rhizomes are much divided and very stout; in several instances they are from 3 to 6 inches below the soil surface. If these turn out to be of the rooting form, we shall have a desirable type of alfalfa very different from any now in cultivation.

## RHIZOMES AND THEIR FUNCTIONS.

The rudiments, at least, of underground rhizomes have been found on all the very hardy species of alfalfa and their numerous forms found in a wild state.

Through hybridization these rhizomes in a modified form are more or less present in nearly all of the hardy and semihardy strains now growing in the United States and Canada. All the strains grown by the writer, including those bred from selected plants by Prof. Wheeler, of South Dakota, and also numerous selected plants of hardy Grimm alfalfas (Pl. VIII, fig. 1) and other varieties secured by Mr. Westgate, of the Bureau of Plant Industry, together with plants secured by the writer from many other sources, show modified rhizomes.

In the greater number of plants the bases from which these underground shoots are produced are several inches beneath the surface.

[1] The letters "F. C. I." stand for "Forage-Crop Investigations," and the numbers refer to the series of plants and seeds used in the investigations of the Office of Forage-Crop Investigations of the Bureau of Plant Industry.

It has also been found that a number of plants produce roots from these modified rhizomes. This peculiarity is responsible for the so-called stooling of many plants in hardy strains. The function of the rhizome and its modifications is undoubtedly to produce a large quantity of growth above ground and to protect the lower winter buds, which are situated well below the surface of the soil, thus providing for the perpetuation of the plant under conditions that are unfavorable for the taller growing forms. In the case of Grimm, F. C. I. No. 138 (Pl. VIII, fig. 1), which has true rhizomes, their function is twofold—that of protecting the buds from extreme cold by burying them several inches beneath the surface and of increasing quickly the area of the crown. Some plants of the Grimm variety which had true rhizomes have been found with crowns 2 feet in diameter. One of the principal functions of the large rhizome development of those varieties recently found in northern Africa may be the storage of water in their underground shoots to tide them over the very hot and dry summers, because the rhizomes of these plants in northern Africa are evidently formed at the close of the growing season, which is during the winter months, but when brought to a colder climate they form during the autumn months. The rhizomes are also instrumental in leaving a large amount of humus in the soil.

In some of the pronounced rhizome-bearing alfalfas taproots are not well developed, but it has invariably been noticed that those with poorly developed or small taproots have a very large number of rhizomes, which when fully developed send down roots of their own to a considerable depth the first season while still attached to the parent plant. Where this occurs the growing end of the rhizome develops branches above the surface. In favorable soil a single plant will cover several square feet of space in one season. Within this period a rooting rhizome has been observed to send down roots to a depth of 30 inches. The growth above ground on this rhizome is frequently as large as that of the original crown during the first season. (Pl. VI.)

### DIFFERENT KINDS OF RHIZOMES.

Asa Gray defines the term "rhizome" as "A rootstock: A stem of rootlike appearance, prostrate on or under the ground, from which rootlets are sent off; the apex progressively sending up herbaceous stems or flowering stalks, and often leaves." The appearance of the rhizomes of the alfalfa during the first stages is, in all the forms noticed, of the same character; that is, they are of rapid development. The internodes are in most cases comparatively short, each one marked at regular intervals by rudiments of leaves and very large

stem-clasping stipular growths. (Pl. II, fig. 2.) When the growing points of these rhizomes approach the surface the stipular growths assume a reddish color and the leaves gradually assume the usual shape. Those rhizomes which are produced on plants, such as the Grimm and Turkestan, often branch out laterally before reaching the surface, but they seldom produce roots. However, they invariably start from the bases of the lower growths of the previous season. At each internode on the rhizome there is a dormant bud closely covered by the lower part of the stipular growth. These enable the plant, after occasional set-backs from unpropitious weather, to branch out from points well under ground. On other plants, such as those commonly found in northern Africa, the rhizomes will frequently travel 3½ feet by the middle of June before coming to the surface, and during their growth underground branching takes place to a greater extent than has been noticed on any other wild alfalfas; but the roots on these alfalfas are not well developed, at least they were not strongly rooted when examined about the middle of July. How they fare later in the season has not been ascertained, but the growths above ground at the period mentioned were not strong. The ground was exceedingly dry, and this would preclude the possibility of rank growth. The growth of this plant as seen under the intense heat and drought of African summers would be a most welcome sight in the semiarid parts of the United States. In some places this plant seemed to revel in what appeared to be almost pure sand.

## ALFALFAS HAVING DEEP-SET CROWNS.

The deep-set crowns of alfalfas have been mentioned in several publications. A plant having this peculiarity attracted the attention of Thomas Le Blanc in England in the last half of the eighteenth century [1] and was found by him to be hardier than plants of *Medicago sativa*. Thus we have a very old record in which hybrid alfalfas with underground shoots were regarded as being hardier than ordinary *M. sativa*.

Brand and Waldron [2] found that at Dickinson, N. Dak., and at Stockton, Kans., the Mongolian alfalfa under very severe tests proved to be the hardiest of any of the newly imported strains, and in both places the crowns were more deeply set in the soil than other varieties. These authors say: "It seems likely that this adaptation, if it may be called an adaptation, is of importance in giving the tenderest part of the plant needed protection."

[1] Miller, Philip. Gardener's and Botanist's Dictionary, 1807.

[2] Brand, C. J., and Waldron, L. R. Cold Resistance of Alfalfa and Some Factors Influencing It. Bulletin 185, Bureau of Plant Industry, U. S. Dept. of Agriculture, 1910, p. 68.

Olin[1] mentions a plant of the Grimm alfalfa and one descended from a plant known as South Dakota No. 167, which showed stooling qualities, but he does not mention this peculiarity as correlated with hardiness. The Grimm alfalfa plant, however, is stated to have had 10 per cent more stems than any other unit plant under study in the nursery.

Some of the wild alfalfas belonging to the rooting-rhizome section are very distinct from the bunching varieties, such as the Peruvian and allied forms, and also from those on the rhizomes of which no roots are formed. On examining a well-developed rhizome-forming plant for the first time one is apt to have but a vague idea of its nature, and it is sometimes probably regarded as a freak. This is not to be wondered at, since no well-defined allusions to rhizomes have been found in treatises on the alfalfas, and yet we meet with fairly numerous instances of rooting rhizomes among the strictly prostrate forms of *Medicago falcata*, once in the Grimm, and always in the forms of *M. sativa gaetula*, and to a limited extent in *M. sativa tunetana* and in one or two others which do not seem to have been described hitherto.

### NONROOTING RHIZOMES.

At least three of the prostrate-growing alfalfas from the Caucasus region produce rhizomatic growths underground. During the two summers since planting, these rhizomatic growths have not produced roots. Like the plants which have rooting rhizomes, the underground growth is made during the autumn months from the bases of the previous summer's shoots. Some of the shoots are only about 3 inches in length and from that to 15 inches. Their growing points appear through the soil surface in early spring and in a short period thereafter a dense carpet of green is produced. This arrangement of the rhizomes is evidently a provision for their protection from severe frosts, as they are found growing at an elevation of 5,000 feet. The immature shoots are thus protected from pasturing animals. The rhizomatic growths in these alfalfas are invariably white in color and not much over one-sixteenth of an inch in diameter.

Numerous semirhizome-producing forms of *falcata-sativa* hybrids behave in a slightly different manner, but on the same general plan as those last mentioned, in that the young shoots for the following season's growth bury their growing points in the soil during autumn and remain buried during winter. In some plants they are not more than 1 inch in length and in others from 2 to 6 inches. Those forms which approach the latter size are usually branched (Pl. IX, fig. 1); the color of the rhizomes is purplish red, more pronounced on the stipular

[1] Olin, W. H. Establishing a Breed of Alfalfa for the Irrigated Lands of Colorado. American Breeders Magazine, vol. 2, no. 4, 1911, p. 284.

parts than on the stems. On the approach of favorable weather the growing points of the rhizomes are inclined toward the surface. Under the influence of light they change from purplish red to dull green, leaves following rapidly on the change of color. A peculiar feature of the rhizomes of this class is found in the very large stipules which sometimes cover a goodly section of the rhizome and which are developed to several times the size of the ordinary stipules (Pl. II, fig. 2). This arrangement of underground growth gives effective protection during winter and abundant space for the development of the shoots above ground.

The common forms of *Medicago sativa* when met with in a semiwild state are seldom of such luxuriant growth as they are under good cultivation. As a consequence, the individual shoots are well developed and the bases are smaller and not crowded. It therefore seems that the plant which develops its growth by means of underground rhizomes, each pointing away from the crown, has the best chance of a long, healthy career in the field. So far as the development of the growth and the consequent longevity of the plant are concerned, it will also be likely to withstand severe winters much better than bunching forms, because the resting buds or partly developed rhizomes are usually protected by the bases of the old growths and commonly by from 1 to 3 inches of soil. It frequently happens in alfalfas having short nonrooting rhizomes that roots will be formed on the prostrate but ripened branches near the crown, as seen in Plate X, figure 1.

## DIFFERENT SEASONS OF GROWTH FOR ABOVEGROUND AND UNDERGROUND STEMS.

The alfalfas of the *sativa* section, which includes the *sativa-falcata* hybrids with the rhizome-forming *falcata* characters predominating, seem to make but little growth above ground after the close of summer, except during wet spells, when the season for growth above ground is slightly prolonged. When, however, the underground growth begins, which it does during the fall, differing in the time of starting with the different varieties, the upper portion of the plant seems to make no progress whatever. All the energies of the plant are directed to the development of underground shoots, which from this period until the beginning of cold weather make very rapid growth.

## VEGETATIVE PROPAGATION OF SELECTED PLANTS.

It is important that an individual alfalfa plant which is an artificial hybrid or one which has been selected from old strains and which has been bred to come true from seed should be raised quickly in large quantities. Raising seedlings from the original plant gives

only a limited number of plants the second season and so on till we find that several years elapse before there is enough seed to sow an acre of ground. In the same period that it takes to raise enough seed to sow an acre it is possible to raise a crop of seed from plants propagated from cuttings that will sow from 10 to 20 times that area. This is accomplished by asexual propagation, not by the division of the roots but by cuttings made from the growing stems above ground. The use of the seed method alone for several generations of increase from a single plant should be abandoned, not only because it is too slow, but because of the danger to which the plants are subjected each year through cross-pollination. Brand[1] unwittingly confuses two very distinct methods of vegetative propagation of individual alfalfa plants—that of propagation by cuttings of the shoots (Pl. VIII, fig. 2) and that of propagation by division of the crowns. It is possible within a year to raise plants from cuttings from a single individual of certain strains to cover more than a quarter of an acre of ground. On the other hand, by dividing a stooling plant—that is, cutting it into pieces—each piece having buds and roots attached, not over 50 plants at the most will be the outcome in the same space of time, and in the bunching plants only a very small number will result.

The method of vegetative propagation worked out by the writer a few years ago has been somewhat improved. When it is desired to grow a large number of plants from a single individual, so that a considerable quantity of seed may be obtained in a reasonably short period, this method may be used to advantage. The cuttings should be made as long as possible, so that several of the buds in the axils of the leaves will be under the ground. This obviously implies that in the rhizome-forming alfalfas branches will be produced from underground buds, thus building up a plant with the lower part of the crown buried in the soil. Cuttings for this purpose are made from 4 to 5 inches in length, all the leaves being removed except three or four at the growing end. The cuttings are quick to root when placed in clean sand. Cold frames and sash are necessary to keep the cuttings from wilting during the rooting process. After rooting they are hardened off, gradually removing the sash. The rooted cuttings can then be placed in a convenient receptacle and planted out in rows which are prepared beforehand. They may be planted with a dibble in much the same way that cabbage seedlings are planted.

## ALFALFA CROSSES.

Many crosses were made during the summers of 1909 and 1910, principally to obtain an abundance of new forms so constituted as to thrive in areas where the common alfalfa does not succeed, and possi-

[1] Brand, C. J. Peruvian Alfalfa: A New Long-Season Variety for the Southwest. Bulletin 118, Bureau of Plant Industry, U. S. Dept. of Agriculture, 1907, p. 27.

bly to shed some light on the parentage of certain strains now growing in different parts of the country. Of some of those which were crossed in 1910 many of the seeds germinated too late in the summer of 1911 to give flowers. However, several plants of each cross flowered and fruited sufficiently to show the nature of the hybrid progeny.

A few of the principal features of the parents and hybrid plants are given in the necessarily brief descriptions of the individuals of each first-generation cross. It should be borne in mind that the descriptions of the individual plants cover only the first summer's growth above ground and also the autumn period when the underground shoots are formed.

It is a very easy matter to raise a hybrid alfalfa, but if it is raised according to the easy way it is worse than useless. The common bumblebee in five minutes will do the work necessary to raise a dozen hybrids, but these hybrids will be trouble mongers. As a rule, only one of the parents is known, which is not sufficient.

To prosecute the work of crossing alfalfas faithfully entails much tedious preliminary work, especially that part which is absolutely necessary, the selection of pure parents. This in itself necessitates self-pollination of their flowers to ascertain whether their progeny comes true to the type selected. If this is not attended to, the operator will often get a hybrid, or at least a seedling likely to be mistaken for a hybrid, which is merely a plant in which expression is given to recessive characters in the parent plants.

## THE DEVELOPMENT OF FIRST-GENERATION SEEDLINGS.

The hybrid progeny resulting from mating two plants each of which has been bred to reproduce true to its own pollen can be depended upon to be intermediate between the parents selected.

This hybrid progeny of the first generation must be self-pollinated and the seeds sown. The seedlings will consist of a large number of varying forms, giving as large a variation as we get in second-generation crosses of the cowpea. All of the varying forms should be subjected to a test for hardiness, which will probably result in a considerable proportion being victims of low temperatures. Individual selections should then be made from the plants which come closest to the ideals of the experimenter. From 10 to 20 plants will be sufficient. The flowers on each plant are again to be self-pollinated and about 100 plants raised from the seeds of each individual. There will be comparatively little variation in the progeny from each second-generation plant in this generation, and the most that can be done is to select those individuals that are similar in every way to the selected plants of the second generation, discarding the

others. The next generation of plants raised from seeds resulting from self-pollinated flowers will give plants that as a rule can be depended upon to come true from seeds, provided that pollen from other strains is excluded. This is the great difficulty to overcome, and its solution is not an easy one. Isolation from other strains is the only practicable way of solving the difficulty. Just how far they should be grown from other strains to preclude the possibility of insects carrying undesirable pollen to the flowers has not yet been determined.

The method of raising new alfalfas was up to a few years ago solely through the agency of insect visitations. It was the only one available and, unfortunately, it is still used, though not to the same extent as formerly. The bumblebee is not discriminating. It may or it may not bring the desired kind of pollen to the stigmas of the flowers of the proposed seed plant, and seeds gathered from them will probably result in many dissimilar plants, to the bewilderment of the experimenters.

## THE TEST OF THE METHOD OF PREPARING FLOWERS FOR CROSSING.

The successful depollination of alfalfa flowers and those of other plants of this family previous to applying foreign pollen to the stigmas may be ascertained by a very easy method and will show the beginner whether the work has been done well or otherwise. It is a test which should be tried by everyone engaged in this line of work.

Select 100 flowers and depollinate by a jet of water, as explained in a recent bulletin of the Bureau of Plant Industry.[1] Allow the stigma to assume its natural position on the banner of the flower, but without the application of pollen to the stigmas. If no seed is produced, then it may be assumed that the depollination was thorough in each case. In the application of water to the stigmas different periods of time may be given four series of 25 flowers each, training the jet of water on the first 25 flowers for a period of 5 seconds, on the next 10 seconds, and on the third and fourth series 15 and 20 seconds, respectively: label each series and note the results, which will serve as a guide for thorough depollination.

## THE SOWING OF THE HYBRID SEED.

As a result of crossing the flowers of any two plants it very frequently happens that but a small number of seeds is secured. In order to get as high a percentage in germination as possible, it is

[1] Oliver, G. W. New Methods of Plant Breeding. Bulletin 167, Bureau of Plant Industry, U. S. Dept. of Agriculture. 1910.

necessary to provide the best conditions, so that every seed will have an opportunity to sprout. This part of the work is just as important and requires as much skill as the actual work of crossing. With alfalfa seed sown shortly after ripening the best results have been obtained with pure sand, covering to a depth of five-eighths of an inch. The receptacles for the soil should be 6-inch flowerpots. If sown in flats, the seeds should be 1½ inches apart in the row and the rows the same distance apart. The reason for wide spacing is that the seeds do not all germinate at the same time; there may be a difference of two to three months between the appearance of the first and last seedlings of a few seeds secured from cross-pollinated flowers. Therefore, the wide spacing gives an opportunity to remove and pot a seedling which appears quickly, without displacing the other seeds. The space from which a seedling has been removed should be marked with a toothpick and the vacant spaces in a partly seeded row should be similarly indicated. It has happened that seeds will lie in the soil for many months without germinating, even under favorable conditions so far as temperature and moisture are concerned. These seeds should be carefully taken up, rubbed gently between two pieces of sandpaper, and resown in pure sand. They will, as a rule, germinate in a day or two, and as soon as the cotyledons reach full size they may be pricked off around the edge of a 6-inch flowerpot.

## PLANTS WITH A POOR POLLEN SUPPLY.

There is abundant evidence to show that the anthers of the flowers of some *Medicago falcata* plants are in many cases either devoid of pollen grains or at most have a very limited supply. The variety of *M. falcata* known as S. P. I. No. 20721 is an example of the latter condition. Insects visiting flowers of *M. falcata* seem to be seldom successful in effecting pollination, as very few flowers on any one plant set seed. During the summers of 1910 and 1911 a large plant of the above serial number did not produce a single pod; it was isolated from other alfalfas, but insects had access to it at all times. It would seem from the correspondence of the Bureau of Plant Industry with observers in the *M. falcata* regions that most forms of this species are more or less shy seeders. There are forms of *M. falcata*, however, which are abundant seed producers and, strange to say, they seem to have pods of the nonshattering form.

## THE DEVELOPMENT OF SEEDLING ALFALFAS.

The manner of the development of growth from the cotyledon stage in spring to the end of the first season or the beginning of cold weather is exceedingly interesting, especially when studied in connection with those hybrids which produce rooting rhizomes.

It is somewhat remarkable to find that the rhizome-forming growth of most plants has its origin in the axils of the seed leaves. Plate VII, figure 2, shows this gradual growth from a seedling in the cotyledon stage to the development of a plant 6 weeks old. Plate VII, figure 2, *A* and *B*, shows a seedling with the cotyledons and one with the first foliage leaf. The subsequent growth of the first shoot above the seed leaves is only a few inches, because its function is to keep at work just long enough to enable the buds on the lower part of the shoot to develop. The seedling at *D* (Pl. VII, fig. 2) shows a bud perfected in the axil of one of the cotyledons before their decay. This seldom happens, because the seed leaves immediately before this stage are little more than breathing surface and keep the plantlet alive, so that the roots and true leaves will be able to take care of themselves. The first lateral growth is usually seen sprouting from the axil of the leaf, with a single blade. Another shoot develops in the axil of the leaf immediately above it. These two shoots make considerable growth, depending upon the variety or species. In this case it is the intention to show merely the beginning of the rhizomatic growth, which develops fully when the seedlings are less than a year old. Plate VII, figure 2, *E*, shows the beginning of the development of the rhizome. These two growths are from the axils of the cotyledons, being formed before their decay. At this stage they necessarily are in a very immature state. Plate VII, figure 1, shows their condition several weeks later. They are then quite large and easily distinguished from the growths above.

It would seem that the main root contracts considerably, or at least sufficiently to enable the part originally occupied by the cotyledons to be drawn below the surface of the soil, because some simple experiments conducted with the object of ascertaining why the neck of the plant is sometimes deep in the soil suggested no other explanation than the contractile nature of the roots.

Out of many thousands of seedlings examined only a single instance has been found where zhizomes were developed below the part originally occupied by the seed leaves. This very remarkable growth occurred in one of the seedlings of cross No. 284, Plate X, figure 2, which shows two rhizomes developing fully 3 inches below the point occupied by the cotyledons. However, when seedling crosses where one of the parents has rhizomes are carefully planted out with the portions occupied by the seed leaves exactly level with the surrounding soil it has almost invariably happened that within six months those parts of the stems formerly occupied by the cotyledons are from 2 to 3 inches below their former levels, while some allowance must be made for the firming of the soil due to beating rains and to other causes.

Those plants which are drawn down into the soil are commonly of the rhizome-producing types. The rhizomes may be anywhere from 3 or 4 inches to 3½ feet in length.

The alfalfa plants which are drawn down into the soil form a considerable proportion of the individuals of the Grimm, Turkestan, Baltic, and Mongolian varieties. These conclusions are drawn from many hundreds of seedlings from hardy strains sent to the writer by Prof. W. A. Wheeler, of Mitchell, S. Dak.

## DESCRIPTIONS OF CROSSES.

### CROSS NO. 191 (MEDICAGO FALCATA, S. P. I. NO. 20721 ♀ × M. SATIVA, S. P. I. NO. 17698 ♂).

The seed-bearing parent, *Medicago falcata* (S. P. I. No. 20721), is one of the tallest of this species. It has been grown on the Department grounds for three seasons. During the first summer it attained a height of 2½ feet, the second season 3½ feet, and during the summer of 1911 it reached a height of 4½ feet. It is a semi-upright plant and belongs to that section of *M. falcata* the plants of which are almost or entirely without rhizomes. The large dormant buds, however, are under the surface of the soil. Late in the season it produces a dense crop of very short growths not over 3 inches in length. The stems of these shoots are not thicker than a pin and the leaves are very small. If this is a normal growth, it would seem to function in the protection of the crown during winter. The root of this plant is the largest of any seen by the writer. In digging to ascertain the depth to which it descends, the task had to be abandoned, because at 8 feet below the surface the roots were still quite large. They probably descend to a depth of over 20 feet.

The pollen-bearing parent is a hardy form of *Medicago sativa* (S. P. I. No. 17698) from Chinook, Mont. It is a bushy upright plant, but it is evidently not a typical *M. sativa*, because seedlings raised from inbred seed showed unmistakable characters indicating that it has a small percentage of *M. falcata* blood in it.

Cross No. 191 is one of the few crosses of which the first-generation plants were invariably alike. From a close scrutiny of the 16 plants raised it was impossible to detect any variation. This is owing to the fact that both parents do not vary from inbred seed, as subsequently proved. Before the flowering period, the 16 plants looked as if they might have been typical *M. sativa;* in fact, it was thought that a mistake had been made. However, when the first flowers opened, this supposition was dispelled. The flower colors of the plants were invariably alike and they resembled the color of the foliage to such an extent that the plants had to be examined closely to find all the flowers. Before and during the flowering period the

first-generation plants were kept in a large wire cage to prevent the flowers being cross-pollinated by insects. The flowers were then tripped by hand and a generous supply of seeds secured.

The second-generation plants were raised during the winter of 1910–11. The progeny of each of the plants of the first generation were kept separate. In this generation the colors of the flowers varied exactly as was expected, ranging from the color of *Medicago falcata* to that of the *M. sativa* parent. The plants of both generations resemble the pollen parent to a much greater degree than the seed parent in so far as habit and foliage are concerned. The general appearance of the flowers and fruit of the parent plants and also those of the first-generation cross is shown in Plate XI, figure 1.

Owing to the numerous progeny of the second generation, the flowers could not be given the same careful treatment to insure self-pollination which was accorded to those of the first generation. However, they were grown in a cool greenhouse and carefully tripped by hand.

The pods of the second generation vary from about two-thirds of a turn to about two turns.

A very noticeable feature in over two-thirds of the progeny of the second generation is the disposition of the plants to form short underground nonrooting rhizomes in autumn immediately after the cessation of top growth. In some of the plants this character is much more accentuated than in others. The plant of *Medicago sativa* from Montana (S. P. I. No. 17698) does not show this character to such a degree as do the hybrid progeny and in the *falcata* parent it is observable only to a very slight degree. It is nevertheless fortunate that the larger number of the second-generation plants have this character, as it obviously means better equipment for northern latitudes. These underground growths are all from the bases of the shoots of the previous summer. They make a horizontal growth of 2 to 3 inches and remain under ground during winter ready to branch out at the surface on the approach of spring. These underground branches even when their tips are within less than half an inch of the surface of the soil do not seem to be injured during cold weather. Some of the plants in large pots have been exposed all winter without any covering and escaped injury although the temperature fell to —13° F. on one or two occasions. With the branches 3 inches below the surface, under good field conditions they will probably stand the lowest possible temperatures of the Northern States. The pollen-bearing *M. sativa* parent from Montana did not have underground growths, but the plant was grown in a large pot in firm soil. Consequently it did not get an opportunity to develop as it would have done had it been planted in the field. The seed-

bearing parent is only fairly well supplied with underground buds, but those examined showed they were not true rhizomes. Perhaps the short rhizomes in the hybrid progeny are due to a latent character in one of the parents. The growth of every one of both the first and second generation plants does not in the least resemble that of the *M. falcata* parent in the development above ground either in the leaf blades or stipules, but the flower color in the first generation is uniformly intermediate between the colors of the flowers of the two parents, and in the second-generation plants the colors range from that of the seed parent through the intermediate shades to that of the pollen parent.

This and other crosses show that if we take an inbred plant of one of the standard varieties of *Medicago sativa* and cross it with all of the many different forms of *M. falcata*, including those with straight and falcate pods, smooth and hairy, upright, decumbent, and prostrate in habit, we will get the basic forms of practically all of the varieties comprising the very numerous and divergent forms common at the present time, which undoubtedly descended from hybrids and which now pass as mere forms of *M. sativa*.

While many crosses raised from the various forms of *Medicago falcata* and *M. sativa* are more or less decümbent, some of the plants of cross No. 191 are upright and very different from the plants of crosses in which other forms of *M. falcata* take a part. From this we must come to the conclusion that the characters of the various forms of *M. falcata* should be carefully studied before the plants are used when upright-growing progeny are wanted. According to the experience gained during the last few years, a dwarf straggling form of *M. falcata* used either as the male or female in a cross will not produce upright progeny, but a plant of *M. falcata* having an almost upright habit, when crossed with an upright *M. sativa*, will give progeny a little less erect than *M. sativa*, but much more erect than the *M. falcata* parent.

### CROSS NO. 284 (GRIMM, F. C. I. NO. 138 ♀ × S. P. I. NO. 28042 ♂).

The pollen-bearing parent of this cross is S. P. I. No. 28042, a large-leaved prostrate plant thought to be *Medicago sativa gaetula*, from the Caucasus Mountains at an altitude of about 4,000 feet. This plant has long rooting rhizomes. The seed parent is a Grimm alfalfa, F. C. I. No. 138 (Pl. VIII, fig. 1), which is possibly one of the few plants of this partly hardy strain which has short rooting rhizomes. It represents what is probably the hardiest of this strain and was selected for breeding, not so much because it was a Grimm alfalfa, but because it was one of the first plants noticed by the writer to have the resting buds several inches beneath the surface of

the soil. This Grimm alfalfa plant has undoubtedly descended from an old strain which originally had the rhizome character much more developed and probably was originally a cross between a *M. sativa* and a semiprostrate rhizome-producing form of *M. falcata.* However, the Grimm alfalfa (F. C. I. No. 138) is possibly a seedling from a very old plant and perhaps one of the original plants resulting from the seed sown in Minnesota which is said to have been brought from Germany in 1857.[1] There seems to be some doubt as to the identity of the pollen-bearing parent, as a description of it does not exactly agree with that of any published species or variety. It seems an intermediate form between *Medicago glandulosa* and *Medicago sativa gaetula.* The flowers are light purple with the exception of the keel, which appears to be light yellow while the flower remains untripped, probably owing to the partly transparent nature of the keel, allowing the color of the stamens to be seen. The pods are much larger than those of *M. sativa* and are densely studded with glandular hairs. The plant is only about 6 inches in height, and during the summer a seedling plant will cover about 4 square feet. The rhizomes are abundant, pure white, and produced in October and the first part of November at Washington, D. C. They push their way to the surface in April, and after leaves are formed they produce roots. The shorter rhizomes come to the surface near the crown, the longer ones appearing farther from the center of the seed-bearing plant.

The plants of the first generation which have flowered, 44 in number, are all hybrids, shown by the fact that the pods have glandular-haired pubescence, resembling in this particular the pollen-bearing parent, while the pods of the parent Grimm alfalfa are smooth. The flower color of the hybrid plants resembles that of the pollen parent. The height of the stems of the tallest plants is about 24 inches, ranging from that to about 15 inches, but consideration must be given to the fact that the plants were set out from 4-inch pots about the middle of May and after ripening a comparatively small number of pods their energies seem to have been spent on the development of an enormous quantity of underground rhizomes. Plate X, figure 2, shows a seedling which began to form rhizomes when only a few weeks from the germinating stage. By the beginning of August some of these rhizomes had well-developed roots with considerable growth above ground. By the end of October the tremendous rhizome formation had ceased and the plant thus assumed its winter stage. (Pl. VI.)

[1] Westgate, J. M. Variegated Alfalfa. Bulletin 169, Bureau of Plant Industry, U. S. Dept. of Agriculture, 1910, p. 21.

This plant far surpasses any other wild or cultivated plant so far observed by the writer in the production of rooting rhizomes. Many of these underground growths are from 2½ to 3 feet in length. The other plants of the same parentage, so far as the development of the underground rhizomes is concerned, have some rhizomes branching to a greater degree than the one mentioned, but they are not quite so long. There is every indication that these plants will cover a larger space than any of the others, either of hybrid origin or otherwise, and owing to the resting buds being very deep in the ground they will probably be very hardy. It is intended to try these and other individuals of the same cross over a wide range of territory as soon as practicable after they have been developed at Washington, D. C., to the third generation, which will take at least two years more to accomplish.

CROSS NO. 289 (GRIMM, F. C I. NO. 131 ♀ × MEDICAGO SATIVA GAETULA, S. P. I. NO. 26590 ♂).

The Grimm alfalfa used as the seed bearer in this cross is quite unlike F. C. I. No. 138 in that it has no rooting rhizomes, but the plant is so deep in the soil that the shoots situated at the lower part of the crown are covered to a depth of from 2½ to 3 inches. It is thus protected during very low temperatures. It was selected by Mr. Westgate from a field of the Grimm alfalfa on Mr. Ensler's farm near Excelsior, Minn., and was chosen by the writer for crossing because of its deep crowns, upright growth, height, and leafiness. *Medicago sativa gaetula* (S. P. I. No. 26590), the pollen-bearing parent, is from Algeria. This plant is probably quite hardy, but of this we have no direct proof, as it seemingly has never been tried in excessively cold regions. It has a very vigorous lot of rhizomes, which are developed early in autumn. These rhizomes are deeply buried in the soil.

From the appearance of the plant in summer one would not imagine it to be a good hay-producing type. However, it promises to be a good plant to grow in light sandy soils in regions where the annual rainfall is light. From the hundreds of resting buds deep in the soil it would seem that it would be unaffected by drought or extreme cold. In the semiarid parts of the country it will probably grow better than any other alfalfa. This supposition is based entirely on its exceedingly long underground rhizomes deep in the ground. These very numerous rhizomes terminate in shoots above ground and eventually produce strong roots. Another good feature is the large number of resting buds at short intervals along the entire length of the rhizomes.

The pods of *Medicago sativa gaetula* are thickly studded with glandular hairs. The flower color is bluish purple tinged with yellow.

*Plant No. 289-3.*—Flowers greenish purple, yellow keels; glandular-haired fruit; foliage bluish green; crowns deep in the soil; short rooting rhizomes. These rhizomes were formed before the plant was 6 months old. Stems and leaves without hairs. Growth made during the first summer, about 18 inches in height.

*Plant No. 289-4.*—Flowers greenish purple; glandular-haired pods; erect habit. The numerous rhizomes were 8 inches long by the beginning of November. Rhizomes begin to send down roots in early spring. Leaves and stems slightly hairy. Growth made during the first summer, 19 inches in height.

*Plant No. 289-5.*—Flowers greenish purple, yellow keels; glandular-haired fruit; foliage bright green; leaves and stems smooth; rhizomes resembling those of the pollen parent in length, but stouter, sending down long roots; growth made during the first season, about 1 foot; scant vegetation above ground, evidently due to enormous rhizome development.

CROSS NO. 293 (GRIMM, F. C. I. NO. 131 ♀ × MEDICAGO FALCATA, S. P. I. NO. 24455 ♂).

The plants of this cross promise to be very cold resistant, as the seed bearer, Grimm alfalfa, was secured from seed gathered from a plant known to be hardy in North Dakota, the flowers of which were self-pollinated; nearly all of the seedlings resemble this plant, especially in their equipment to stand very cold weather.

The pollen-bearing parent is S. P. I. No. 24455, a form of *Medicago falcata* found by Prof. Hansen north of Semipalatinsk, western Siberia. It is stated that plants of this form were found with stems 5 feet 8 inches long.[1]

*Plant No. 293-1.*—The flowers of this plant are greenish purple; stems 20 inches tall; slightly decumbent; no underground rhizomes present, but there are numerous short shoots at the bases of the summer's growths. The crown is low down in the soil.

*Plant No. 293-3.*—Flowers greenish purple; crown deeply set in the soil; goodly supply of stout, short branching rhizomes, which in October point downward in the soil; stems and leaves smooth; height, 18 inches.

*Plant No. 293-5.*—Flowers greenish purple; very stout branching rhizomes. During summer the bases of the shoots produced numerous roots when the plants were 5 months old. Height of growth, 20 inches; stems and leaves smooth; promises to form very large crowns.

[1] Willis, C., and Bopp, J. B. Progress in Variety Tests of Alfalfas. Bulletin 20, South Dakota Agricultural Experiment Station, Brookings, S. Dak.

CROSS NO. 294 (GRIMM, F. C. I. NO. 131 ♀ × S. P. I. NO. 28042, PLANT NO. 6 ♂).

The Grimm alfalfa seed bearer in this cross is the same as used in cross No. 293. The pollen-bearing plant was found in the Caucasus region at an elevation of 4,000 feet and is therefore assumed to be hardy. If the depth of the rooting rhizomes of wild plants is an indication of the hardiness of a plant, this ought to be an exceptionally hardy strain and probably also drought resistant.

*Plant No. 294-1.*—Flowers very light purple, with yellow keels. Fruits profusely covered with glandular pubescence; crowns deeply set in the soil; growth 18 inches tall; upright; no rhizomes; branches of crown rooting at a point from 1 to 2 inches above top of taproot.

*Plant No. 294-2.*—Flowers light purple, keel yellow; pods large, with glandular hairs; free seeding; no rhizomes; crown of plant low down in the soil.

*Plant No. 294-3.*—Flowers purple, keel yellow; glandular hairs on fruit; height of plant 18 inches; stems and leaves smooth; very heavy crop of rhizomes, all of them very stout and much branched; some of the most advanced in growth produced roots before the advent of cool weather.

*Plant No. 294-4.*—Flowers light purple, not changing in color; pods with glandular hairs; plant erect; height of growth the first season 18 inches; very thick branching rhizomes starting at a point 3 inches beneath surface of soil.

CROSS NO. 295 (GRIMM, F. C. I. NO. 131 ♀ × MEDICAGO FALCATA, S. P. I. NO. 24455 ♂).

For description of parents, see cross No. 293.

*Plant No. 295-1.*—Flowers almost yellow, faintly shaded with purple; very short rhizomes; crown deeply set in soil. The rhizomes begin from a point 4 inches below the surface. Height 20 inches. A promising plant.

*Plant No. 295-3.*—Flowers almost yellow, faintly purple on opening, changing to green with age; rhizomes very short, but forming roots and tops the first season; crown 8 inches in diameter when seven months from the seedling stage. A promising hardy form.

*Plant No. 295-4.*—Flowers yellow, faintly purple on opening, changing to purplish green; of upright growth; 20 inches in height during first season; leaves and stems smooth; crown deeply set in soil; strong rhizomes formed in October from a point 4 inches below surface of soil. A promising hardy form.

CROSS NO. 299 (PERUVIAN, G. AND G. NO. 60 ♀ × S. P. I. NO. 28042 ♂).

The seed-bearing parent of cross No. 299 is a typical Peruvian alfalfa from Yuma, Ariz. (Pl. V, fig. 2.) This variety is characterized by a strong upright growth and hairy stems and leaves. The

crown of the plant is usually at or very near the surface of the soil. It is a comparatively tender strain, although it has withstood the cold of several mild winters at Washington, D. C. It has been shown to be capable of withstanding a lower temperature during the development of growth at Yuma, Ariz., than any other variety.[1] The very hairy stems and leaves in all probability have something to do with its ability to stand low temperatures when growing.

The pollen-bearing parent, S. P. I. No. 28042, is a dwarf-growing plant from the Caucasus region at an elevation of 4,000 feet. It has bicolored flowers. The banner and wings are light purple and the keel is yellowish. The pods are almost as large as the variety of *Medicago sativa* known as *tunetana*. The pods also resemble those of *M. sativa tunetana* in that they have glandular hairs.

*Plant No. 299-1.*—Flowers very light purple, yellowish keel; pods with glandular pubescence; height of growth during first season 24 inches; young stems purplish; leaves and stems hairy, plainly showing the blood of the Peruvian variety. The transmitted male characters are noticeable in the yellowish keel of the flower and the very thick and long rooting rhizomes. Growth upright, strong. The rhizomes averaged about 15 inches in length by the end of October, making a crown over 2 feet 6 inches in a single summer. This plant promises to form a very much larger crown in a short period. It will possibly be much hardier than the typical Peruvian variety. It seems peculiarly well suited for growing in warm areas where irrigation is lacking, but it remains to be seen just how this alfalfa will behave in the field, as the profusely developed underground rooting rhizomes are exceedingly robust. There is no doubt that the blending of these two plants will result in a strain to outward appearances somewhat like the Peruvian, but with thoroughly protected underground parts.

There are 26 other plants of this cross, the seeds of which germinated late in the season and which have not bloomed, but their characters so far indicate that they are more or less like plant No. 299-1.

CROSS NO. 300 (PERUVIAN, G. AND G. NO. 60 ♀ × MEDICAGO FALCATA, S. P. I. NO. 24455 ♂).

The seed bearer, No. 60, is a typical Peruvian from the original plants which withstood several winters at Washington, D. C. It is not provided with underground rhizomes and the resting buds are fully exposed during the winter. As it is a strictly upright and tall-growing form, it was selected for crossing with one of the very hardy

[1] Brand, C. J. Peruvian Alfalfa: A New Long-Season Variety for the Southwest. Bulletin 118, Bureau of Plant Industry, U. S. Dept. of Agriculture. 1907.

forms of *Medicago falcata* (S. P. I. No. 24455, Pl. X, fig. 1) brought by Prof. Hansen from a district in Siberia where the mercury is said to freeze in the thermometers with no snow on the ground.[1] This form of *M. falcata* is comparatively low growing at Washington, D. C. It was planted alongside S. P. I. No. 20721. Its greatest height in two years amounted to only about 12 inches. The broad crown of the plant is deep in the soil, and numerous but very short growths are made in the autumn from the lowest buds. It was crossed on Peruvian to ascertain the result of a union between one of the tenderest and one of the hardiest of the alfalfas.

*Plant No. 300–1.*—Flower, greenish purple with slight traces of yellow; stems and leaves hairy. This plant has the crown exposed above the surface of the soil, showing the character of Peruvian alfalfa in this respect. No rhizomes; height 24 inches.

*Plant No. 300–5.*—Greenish yellow flowers; stipules not fringed at base. Although Peruvian alfalfa was the seed plant, there is no trace of it in the stems and leaves of this first-generation plant, it being absolutely without hairs, both on stems and leaves. This plant was put out too late to flower. It produces roots in abundance from the bases of the shoots during September. Seemingly a large-crowned form.

#### CROSS NO. 309 (S. P. I. NO. 28042 ♀ × F. C. I. NO. 131 ♂).

S. P. I. No. 28042 has already been described in former crosses.

Grimm, F. C. I. No. 131, was selected for its deep-rooting crown, the base of which was nearly 3 inches below the surface of the soil.

*Plant No. 309–3.*—The only plant which has flowered so far has light-purple and yellow flowers and glandular-haired pods. It is a semiprostrate form, very abundantly supplied with much-branched underground rooting rhizomes. (Pl. IX, fig. 2.) It promises well for intermountain areas. Out of the cross there are 13 plants which have not yet flowered. All of them have comparatively small round leaflets.

#### CROSS NO. 318 (GRIMM, F. C. I. NO. 269 ♀ × S. P. I. NO. 28042 ♂).

The Grimm parent of this cross is a second-generation seedling of F. C. I. No. 138, which has its resting buds deep in the soil. It was selected by the Office of Forage-Crop Investigations on account of extreme hardiness and number of stems. The pollen parent is S. P. I. No. 28042, which has been described in some of the foregoing crosses.

*Plant No. 318–1.*—Rose-purple flowers; pods with glandular hairs.

[1] Hansen, N. E. The Wild Alfalfas and Clovers of Siberia, with a Perspective View of the Alfalfas of the World. Bulletin 150, Bureau of Plant Industry, U. S. Dept. of Agriculture. 1909.

The crown of this plant is well protected by being from 2½ to 3 inches deep in the soil. Roots are developed from the bases of branches during the first season. (Pl. I, fig. 2.)

*Plant No. 318-2.*—Not yet flowered; rhizomes poorly developed; stems and leaves smooth; well protected by deep-rooted crowns.

*Plant No. 318-3.*—Light-purple flowers; pods with glandular hairs; strong rooting rhizomes; medium-good upright growth. The plant has a deeply seated crown.

*Plant No. 318-4.*—Greenish purple flowers; glandular-haired pods; long, creeping rhizomes well under the ground, the best plant of the cross in this respect. Plant upright in growth.

*Plant No. 318-5.*—Very light purple flowers; glandular-haired pods; stems almost smooth; dwarf, bushy; no rhizomes.

*Plant No. 318-6.*—Light-purple flowers; glandular-haired pods; a bushy, upright plant with a few short rhizomes.

*Plant No. 318-8.*—Flowers very light purple and yellow; glandular-haired pods; plant strictly upright, 18 inches tall, stems and leaves slightly hairy. This plant has the base of the crown at the surface.

CROSS NO. 320 (S. P. I. NO. 28042 ♀ × PERUVIAN, G. AND G. NO. 60 ♂).

This is very decidedly an instance in which some of the principal characters of the male parent preponderate over those of the female in the first-generation plants.

S. P. I. No. 28042, the seed bearer of the above cross, has glandular-haired pods and a more or less procumbent habit, with a generous supply of underground rooting rhizomes. The flowers are large, light purple in color except the keel, which has a yellowish cast. This plant was collected between Dushet and Passanaura, Caucasus, Russia, at an altitude of 4,000 feet. It bloomed in June, 1910. Pollen from No. 60, a Peruvian plant, was applied to the stigmas of the glandular-haired plant. During the first few months after the resulting seeds germinated the growth of the hybrid progeny so closely resembled the pollen parent that at first the writer thought that a mistake had been made and that the seedlings were of the typical Peruvian alfalfa. The appearance of the flowers, however, dispelled this belief, because they resembled the color of those of the female parent. As the fruit approached maturity they were found to be thickly studded with glandular hairs, which is another character of the seed-bearing parent.

As the resting period approached, the plants developed numerous and very strong underground rhizomes. Thus it will be seen that three of the important characters were transmitted by the seed bearer to the hybrid progeny, viz, the glandular hairs, flower color, and

rhizome development, while the pollen-bearing parent[1] transmitted upright stems, which, together with the leaves, are quite hairy and have a remarkable likeness to the Peruvian alfalfa.

It will be interesting to ascertain to what extent the male has transmitted its hardy nature to the hybrid progeny, as the underground parts of the plants are evidently perfectly equipped to withstand winters of a much more searching nature than the conditions prevailing where the Peruvian alfalfa succeeds best.[2] Very large branching underground rhizomes have been formed low down below the crowns of some of the plants. Other plants have unbranched rhizomes. These rhizomes seem to function in insuring a liberal supply of shoots at the commencement of the growing season. However, it is yet too early to judge of their nature in this respect. There can be no doubt, however, that these plants will each cover a considerable area of ground in one or two seasons.

*Plant No. 320-1.*—Stems upright; 3 feet in height; color of flowers light lavender; glandular-haired pods; no rhizomes. The crowns are deeply situated in the soil.

*Plant No. 320-3.*—Stems and leaves hairy; very large rooting rhizomes; crowns 8 inches in diameter at end of first season; pods with glandular hairs.

CROSS NO. 321 (GRIMM, F. C. I. NO. 135 ♀ × S. P. I. NO. 28042 ♂).

The seed-bearing parent is a plant which has the crown deep in the soil. A 1-year-old plant develops a crown about 8 inches across. Some of the principal divisions of the crown develop fairly large roots. S. P. I. No. 28042 is a plant with very abundant rooting rhizomes and prostrate habit.

*Plant No. 321-1.*—The Grimm parent is not an inbred plant; consequently the hybrid progeny has no resemblance to it. Its appearance is more like that of a Turkestan variety. The pollen-bearing plant has transmitted its rhizome-forming character and large glandular-haired pods.

CROSS NO. 322 (GRIMM, F. C. I. NO. 135 ♀ × S. P. I. NO. 28041 ♂).

The Grimm is the same plant used as seed bearer in cross No. 321.

S. P. I. No. 28041 is a semiprostrate plant found in the Caucasus Mountains. The flowers are very dark blue and very small. The pods are smaller than those of *Medicago cancellata* and quite black

[1] This plant is from a rooted cutting from the individual plant of the Peruvian alfalfa from which pollen was taken in raising the first alfalfa hybrid by the now generally adopted method described in Bulletin 167, Bureau of Plant Industry, U. S. Dept. of Agriculture, entitled "New Methods of Plant Breeding." 1910.

[2] Brand, C. J. Peruvian Alfalfa, a New Long-Season Variety for the Southwest. Bulletin 118, Bureau of Plant Industry, U. S. Dept. of Agriculture. 1907.

in color. The plant is provided with a large number of long rooting rhizomes.

*Plant No. 322-2.*—All of the plants in this cross germinated late and did not flower in 1911. All of them have growth very much resembling that of *Medicago lupulina* above ground. Rhizomes fairly well developed under ground.

CROSS NO. 323 (S. P. I. NO. 25733 ♀ × S. P. I. NO. 28041 ♂).

S. P. I. No. 25733, the seed-bearing parent, is a form of *Medicago sativa* from Bridgeport, Kans.

S. P. I. No. 28041 is the same plant used as the pollen bearer in Cross No. 322.

*Plant No. 323-1.*—Flowers purple; glandular hairy pods; plant procumbent in habit; short rhizomes; crown deeply seated.

*Plant No. 323-2.*—Flowers purple; glandular hairy pods; leaves and stems smooth; growth straggling; supplied with a large number of short rooting rhizomes; height 18 inches; crown deeply seated.

*Plant No. 323-3.*—Flowers bluish purple; stems and leaves smooth; crown deeply set in soil.

*Plant No. 323-4.*—Not in flower; crown 2 inches below the surface; stems and leaves resembling those of Peruvian alfalfa; height of growth first season, 2 feet.

CROSS NO. 336 (S. P. I. NO. 26667 ♀ × S. P. I. NO. 26865 ♂).

The seed bearer, S. P. I. No. 26667, is a dwarf form of *Medicago falcata* from the Crimea, with straight smooth pods and light-yellow flowers. It is provided with a fair number of rhizomes near the surface of the ground. (Pl. IV, fig. 2.) The pollen-bearing parent, S. P. I. No. 26865, is from the Caucasus region and is a taller growing form of *M. falcata*, with straight hairy pods. The growth above ground is somewhat sparse, owing to the specimen received being small, but the new rhizomes are very abundant. The cross was made to ascertain whether a hybrid could be secured which could be used as a reliable pasture plant; that is, an alfalfa with short, dense growth and an abundant supply of underground rooting rhizomes. Some of the progeny are exceedingly promising. (Pl. III, fig. 1.)

*Plants Nos. 336-1-32.*—About 5 inches in height. The leaves are short and smooth, very close together on the stems, and bluish green in color. Most of the rhizome-forming alfalfas produce the principal crop of rhizomes in the autumn or late summer. This plant seems to stop growing only when the ground is frozen hard. It is also the first alfalfa to begin growing, as it is quite green in March. It produces rhizomes throughout the growing season. It looks exceedingly promising as a pasture plant because when shorn of all the stems and

foliage above ground and down to a depth of 1 inch beneath the surface it soon recuperates and throws up numerous growths in a few days. The rhizomes are different from those of any other alfalfa noticed by the writer in that they send out roots along their entire length (Pl. III, fig. 2). Some of them have measured 3 feet in length. Rhizomes formed from the seedlings planted out in the summer of 1910 were found in the autumn of 1911 to have pierced the soil to a depth of over 12 inches. Plate III, figure 2, shows two pieces of rhizomes found at this distance below the surface. New rhizomes are seen sprouting from the old ones, proving that dormant buds deep in the soil are ever ready to send up new rhizomes to the surface. Each rhizome develops several branches. This is the easiest alfalfa to propagate vegetatively of all those with which we have experimented.

Several hundred cuttings were rooted in August, 1910. These were put in 5-inch pots and placed in an open frame. In numerous instances during the winter, mice had eaten the crowns of the plants, but this does not seem to have harmed the rhizomes in the least, as they were advanced to such a stage that roots were formed, and in the following summer a single plant in enriched rotten-granite soil covered a space of about 9 square feet. The growth during the first season is comparatively sparse, but dense enough to give abundant grazing material.

This hybrid does not take kindly to heavy clay-loam soils. It evidently prefers a soil which the rhizomes can pierce easily.

The rhizomes of this prostrate alfalfa are very different from those of all other species and forms in that roots are not produced at irregular intervals. On the contrary, as seen in Plate III, figure 2, at every internode numerous small roots are formed, some of which become fairly large the first season, especially after the foliage is produced. When the first growth is fairly well matured, other rhizomes form at a point between 2 to 3 inches from the surface, gradually but surely widening the area of growth. Plate V, figure 1, shows two cuttings only a few weeks old developing rhizomes.

### CROSS NO. 389 (S. P. I. NO. 24455 ♀ × S. P. I. NO. 17698 ♂).

The seed bearer, S. P. I. No. 24455, is one of the very hardy forms of *Medicago falcata* procured by Prof. Hansen during his last trip to Siberia. Although it has been planted out for nearly three years alongside S. P. I. No. 20721, unlike the last named it does not grow to be over 12 inches high. It looks to be very hardy, however, judging from the numerous short underground rhizomes.

The pollen-bearing parent, S. P. I. No. 17698, is a plant of *M. sativa* from Chinook, Mont.

*Plant No. 389-2.*—The hybrid is upright growing with rather thin, wiry smooth stems, which with the rather small leaves would almost be taken for a plant of the Grimm alfalfa. It has not produced flowers thus far. The first-generation plants are very different from those of cross No. 191, which is between S. P. I. No. 20721 and the plant which is the pollen parent of the above cross. The plant is well protected during winter by very numerous short rhizomes, which are placed several inches under ground. The plants of this cross were all late in germinating. It is a promising combination for areas with very severe winters.

## SUMMARY.

Among the large number of distinct forms of alfalfa collected mainly through the Office of Foreign Seed and Plant Introduction, some of the plants have revealed underground rhizome-forming characters which seem to be correlated with drought and cold resistance.

Modifications of these characters have been found in some of the cultivated strains, such as the Grimm, Baltic, Turkestan, and Mongolian alfalfas.

In the more tender alfalfas, such as the Peruvian, these characters seem to be absent.

Many crosses have been made between recently discovered rhizome-forming alfalfas and some of the standard varieties, not so much to improve the strains of alfalfa now growing in the alfalfa regions of the United States as to provide pasturage forms which will grow in areas not now suited to the needs of the standard varieties.

# PLATES.

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## DESCRIPTION OF PLATES.

PLATE I. Fig. 1.—A plant of *Medicago sativa gaetula* from northern Africa. In this plant the rhizomes are well developed, the branch at the left being more than 3 feet 6 inches long. The plant is about 2 years old and was found growing in soil composed largely of decomposed rock. This variety may be found to be valuable in the intermountain areas. Fig. 2.—A plant of cross No. 318. Seedling of Grimm, F. C. I. No. 131 ♀ × S. P. I. No. 28042 ♂. The pollen parent is from the Caucasus Mountains at an elevation of 4,000 feet. The seed parent was selected from a field of Grimm alfalfa on Mr. Ensler's farm near Excelsior, Minn., by Mr. J. M. Westgate, of the Bureau of Plant Industry. The seedling Grimm does not have rhizomes, but the male parent is well supplied with rooting rhizomes. In the hybrid the rhizomes are well under the surface of the soil.

PLATE II. Fig. 1.—A plant of *Medicago falcata*, showing a taproot over 5 feet in length, diminishing in diameter very slightly when more than 5 feet below the surface. This plant has pods of the nonshattering form, which makes it valuable for future breeding. Fig. 2.—Nonrooting rhizomes of *M. sativa turkestanica*, showing the gradual development of leaves.

PLATE III. Fig. 1.—A plant showing rhizomatic growth of cross No. 336 (S. P. I. No. 26667 ♀ × S. P. I. No. 26865 ♂), winter condition. All of the rhizomatic growth was developed before the end of October. This cross promises well as a pasture alfalfa. Fig. 2.—Rhizomes of alfalfa cross No. 336 (S. P. I. No. 26667 ♀ × S. P. I. No. 26865 ♂). Rooting rhizomes nearly 2 years old sending out new rhizomes. The dormant buds on the old rhizomes are plainly seen. These rooting rhizomes and resting buds were found 12 inches under the surface of the soil.

PLATE IV. Fig. 1.—A plant of cross No. 336, showing recovery from a severe test which involved cutting the growth 1 inch below the surface of the soil six times during the summer. Fig. 2.—A plant of *Medicago falcata* (S. P. I. No. 26667) from the Crimea; seed-bearing parent of cross No. 336. This plant grows a little over 6 inches high and makes a very dense growth. It may be drought resistant.

PLATE V. Fig. 1.—Rooted cuttings of pasture alfalfa cross No. 336 seven weeks after removal from propagating bed, showing rhizome development. The cuttings rooted in eight days after being placed in sand. Their condition a few months later is seen in Plate III, figure 1. Fig. 2.—A seedling Peruvian alfalfa plant, showing dormant buds unprotected. The crown is above the surface of the soil. This strain is one in which no rhizome-forming influence is apparent. The rhizome-forming alfalfas continue growing long after the Peruvian variety has become dormant at Washington, D. C., but while the growth is generally very abundant it is hidden from view. This fact may explain why the Peruvian alfalfa, which has no underground shoots, has a lower zero point of growth above ground than other alfalfas.

PLATE VI. Plant No. 7 of cross No. 284 (Grimm alfalfa, F. C. I. No. 138 ♀ × S. P. I. No. 28042 ♂.) This plant is seven months from the seed. Some of the rhizomes are more than 3 feet long. One of the oldest rhizomes has developed branches and roots.

PLATE VII. Fig. 1.—A seedling of *Medicago sativa gaetula*, showing the beginning of rhizome growth. The lower buds are 1 inch below the surface of the soil. Fig. 2.—Seedling stages of a rhizome-forming alfalfa (*M. sativa gaetula*). *A*, Seedling with cotyledons developed. *B*, In the second stage the second leaf has only one blade; the next is trifoliate. *C*, Six leaves are seen on the first shoot, the stipules are plainly noticeable, and bacterial tubercles are seen on the root. *D*, The first shoot is nearing its maximum size and is becoming decumbent. The second shoot is starting from the base of the simple leaf. A bud in the axil of the cotyledon at the left may be plainly seen. *E*, Seedlings before attaining this size usually lose their seed leaves. The primary shoot has completed its growth, the secondary shoot from the axil of the simple leaf has made rapid progress, and the buds in the axils of the cotyledons have made considerable progress. The future rhizomes develop from the leaves of these two shoots.

PLATE VIII. Fig. 1.—Inbred seedling of Grimm alfalfa, F. C. I. No. 138. The seed-bearing parent of this plant withstood the winters of Minnesota since the introduction of the Grimm in 1857. The lower part of the crown is well beneath the surface of the soil. The short rooting rhizomes penetrate the soil to a depth of several inches. The crown of this plant spreads rapidly. Fig. 2.—Rooted cuttings of rhizome-forming and nonrhizome-forming alfalfas, three months from the cutting stage. *A*, *Medicago sativa gaetula; B*, Grimm, F. C. I. No. 131. At the lower part of the stem of *M. sativa gaetula* a rhizome has formed three branches, two of which have produced growth above ground. The third branch has descended into the soil. In the Grimm plant no rhizomes have formed and all the growth is above ground.

PLATE IX. Fig. 1.—A 6-months-old plant of Baltic alfalfa (No. C–25 Wheeler). Probably one of the parents of this plant was well supplied with rooting rhizomes. The rhizomes are well under the surface of the soil, and roots will evidently be produced the following season, making a very broad crown in course of time. Fig. 2.—A plant of cross No. 309 (*Medicago sativa gaetula*, S. P. I. No. 28042 ♀ × Grimm, F. C. I. No. 131 ♂). In early autumn the cessation of growth is quite sudden, but for several weeks later the underground rhizomes continue to develop.

PLATE X. Fig. 1.—A plant of *Medicago falcata* (S. P. I. No. 24455) 18 months from seed, one of the hardiest alfalfas. During the first season considerable stooling takes place. During the second season, as the crown enlarges, numerous strong anchor roots are developed, precluding any possibility of heaving. Fig. 2.—One of the original seedlings of cross No. 284 two months after germination. This seedling has developed two rhizomes fully 3 inches below the cotyledon scars and in itself tells the story of the hardy alfalfa, because even in this early stage the dormant buds have 3 inches of soil protection during the winter months.

PLATE XI. Fig. 1.—Flowers and pods of cross No. 191 (*Medicago falcata*, S. P. I. No. 20721 ♀ × *M. sativa*, S. P. I. No. 17698 ♂). Enlarged two diameters. The first flower and pod are from *M. falcata* (S. P. I. No. 20721). The flower and pod in the middle of the illustration are *M. sativa* (S. P. I. No. 17698). The hybrid (first generation) is seen in the flower and pod to the right. Fig. 2.—A plant of *M. sativa* (S. P. I. No. 28152), a wild rhizome-forming form from the Caucasus region.

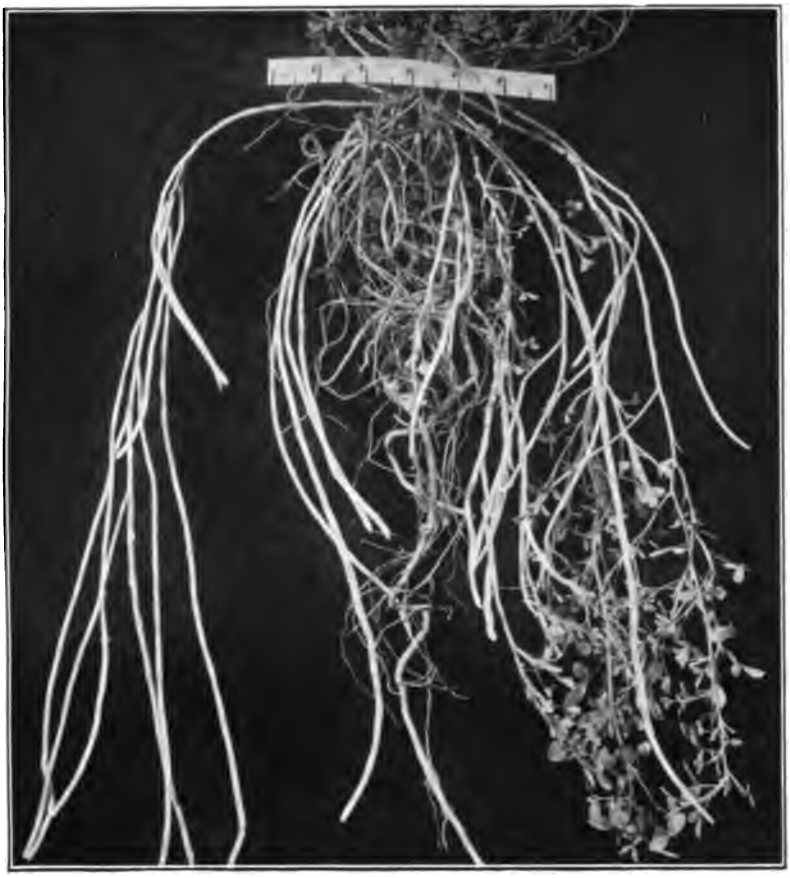


FIG. 1.—A PLANT OF MEDICAGO SATIVA GAETULA, SHOWING RHIZOMES 3 FEET 6 INCHES IN LENGTH.

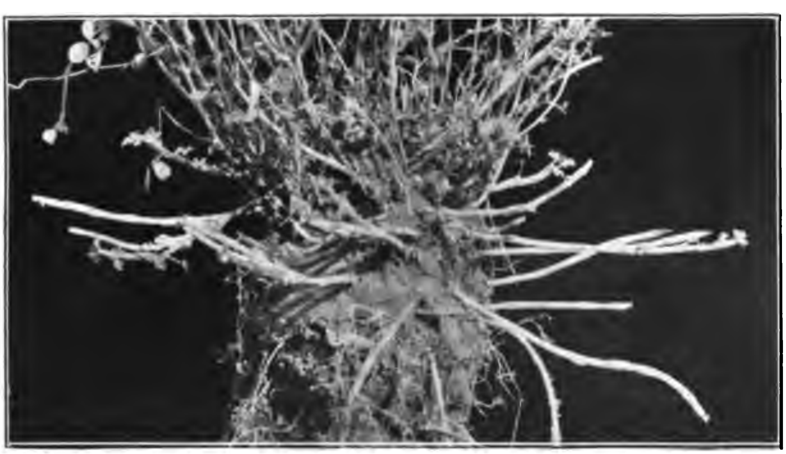


FIG. 2.—A PLANT OF CROSS NO. 318 6 MONTHS FROM THE SEEDLING STAGE.
Grimm, F. C. I. No. 131 ♀ × S. P. I. No. 28042 ♂.

FIG. 1.—A PLANT OF MEDICAGO FALCATA, SHOWING A TAPROOT OVER 5 FEET IN LENGTH. DIMINISHING BUT SLIGHTLY IN DIAMETER.

FIG. 2.—NONROOTING RHIZOMES OF MEDICAGO SATIVA TURKESTANICA, SHOWING THE DEVELOPMENT OF LEAVES.

FIG. 1.—A PLANT SHOWING THE RHIZOME GROWTH OF CROSS NO. 336, WINTER CONDITION.

S. P. I. No. 26667 ♀ × S. P. I. No. 26865 ♂.

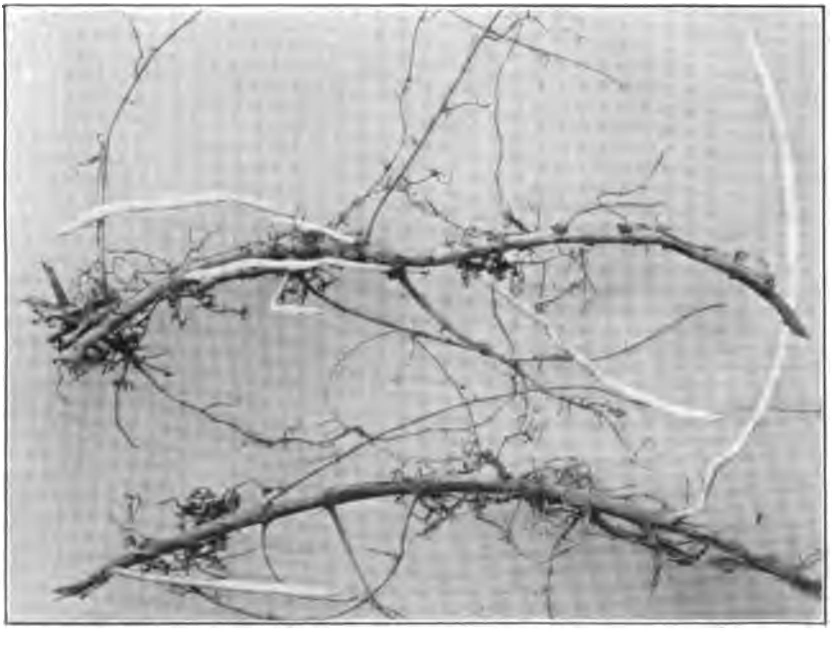


FIG. 2.—RHIZOMES OF ALFALFA CROSS NO. 336, WITH RESTING BUDS 12 INCHES BELOW THE SURFACE OF THE SOIL.

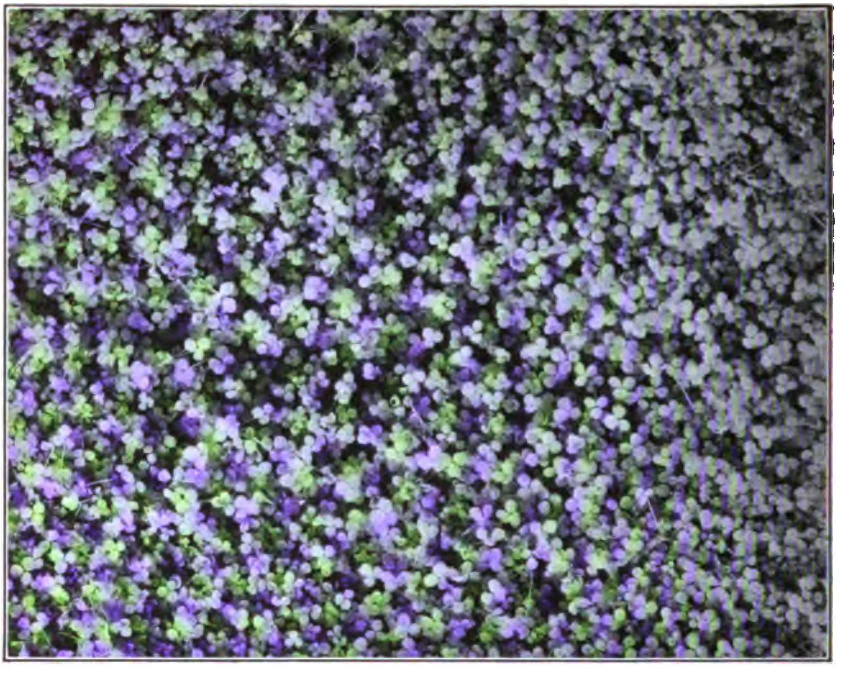


FIG 1.—A PLANT OF CROSS NO. 336, SHOWING RECOVERY AFTER A SEVERE CUTTING TEST.

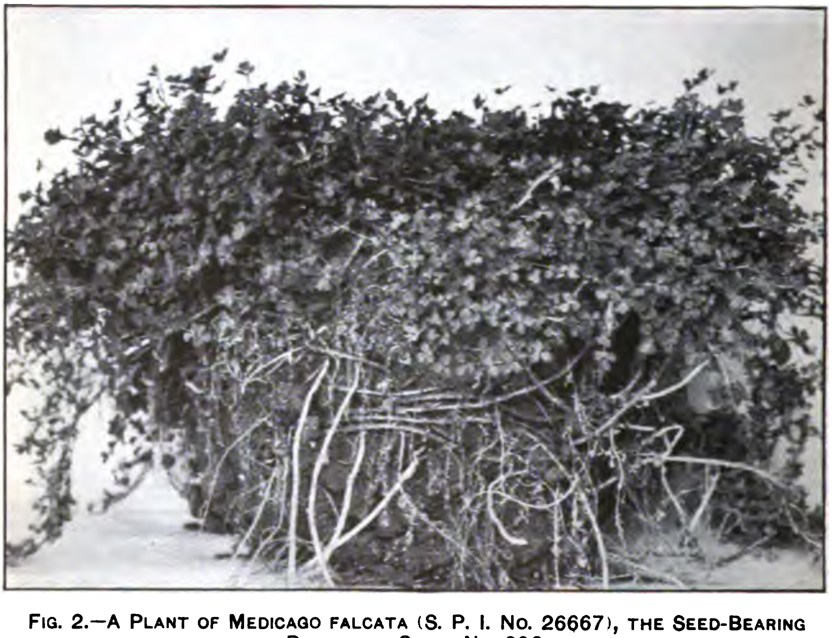
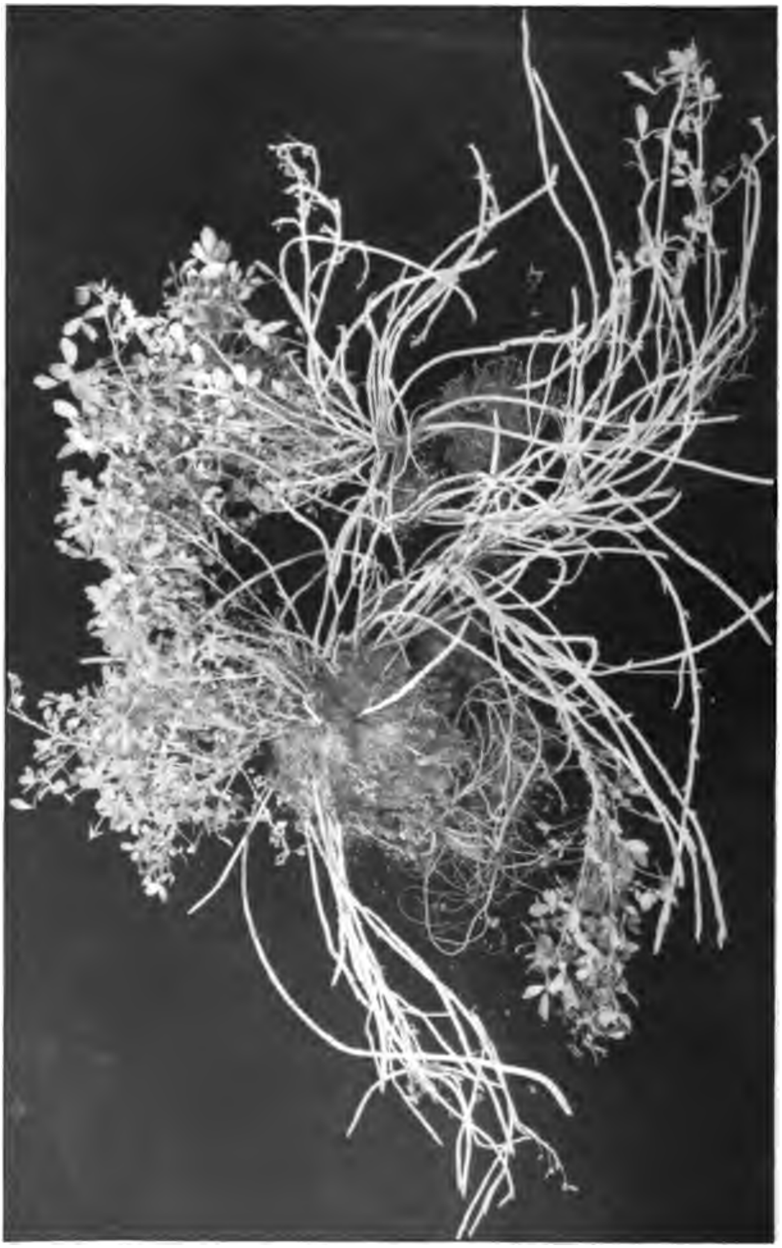


FIG. 2.—A PLANT OF MEDICAGO FALCATA (S. P. I. NO. 26667), THE SEED-BEARING PARENT OF CROSS NO. 336.

FIG. 1.—ROOTED CUTTINGS OF CROSS NO. 336, SHOWING THE BEGINNING OF RHIZOME GROWTH.

FIG. 2.—A SEEDLING PERUVIAN ALFALFA PLANT, SHOWING DORMANT BUDS UNPROTECTED.



PLANT NO. 7 OF CROSS NO. 284.

Grimm alfalfa, F. C. I. No. 138 ♀ × S. P. I. No. 28042 ♂.

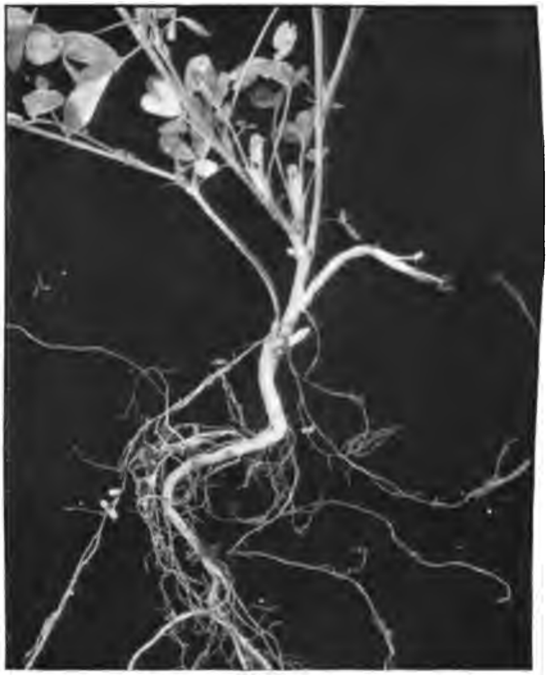


FIG. 1.—A SEEDLING OF MEDICAGO SATIVA GAETULA, 7 WEEKS OLD, SHOWING THE BEGINNING OF RHIZOME GROWTH.


FIG. 2.—SEEDLING STAGES OF A RHIZOME-FORMING ALFALFA.

FIG. 1.—A PLANT OF GRIMM ALFALFA (F. C. I. No. 138), ONE OF THE HARDIEST OF THIS STRAIN.


FIG. 2.—*A*, A ROOTED CUTTING OF RHIZOME-FORMING ALFALFA. *B*, A ROOTED CUTTING OF ALFALFA NOT FORMING RHIZOMES.

FIG. 1.—A PLANT OF BALTIC ALFALFA (NO. C-25, W. A. WHEELER), AN IDEAL TYPE FOR VERY COLD REGIONS.

FIG. 2.—A PLANT OF CROSS NO. 309, WINTER CONDITION.
*Medicago sativa gaetula*, S. P. I. No. 28042 ♀ × Grimm, F. C. I. No. 130 ♂.

FIG. 1.—A PLANT OF MEDICAGO FALCATA (S. P. I. NO. 24455) 18 MONTHS FROM SEED; ONE OF THE HARDIEST ALFALFAS.

FIG. 2.—A SEEDLING OF CROSS NO. 284, SHOWING RHIZOMES DEVELOPING 3 INCHES BELOW THE CROWN 2 MONTHS AFTER GERMINATION.


FIG. 1.—FLOWERS AND PODS OF CROSS NO. 191. *A* AND *B*, PARENTS; *C*, HYBRID.
(Enlarged two diameters.)

FIG. 2.—A PLANT OF MEDICAGO SATIVA (S. P. I. NO. 28152), A PROSTRATE FORM WITH ROOTING RHIZOMES, AUTUMN CONDITION.

Issued October 2, 1912.

U. S. DEPARTMENT OF AGRICULTURE.

BUREAU OF PLANT INDUSTRY—BULLETIN NO. 259.

B. T. GALLOWAY, *Chief of Bureau.*

# WHAT IS FARM MANAGEMENT?

BY

W. J. SPILLMAN,

*Agriculturist in Charge of the Office of Farm Management.*

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1912.

## BUREAU OF PLANT INDUSTRY.

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# LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
BUREAU OF PLANT INDUSTRY,
OFFICE OF THE CHIEF,
*Washington, D. C., May 29, 1912.*

SIR: I have the honor to submit herewith a manuscript entitled "What is Farm Management?" and to recommend its publication as Bulletin No. 259 of the series of this bureau.

Farm management as a science and as a subject of investigation is new, and there is an insistent demand for information that will assist those who are engaged in teaching the subject, as well as those who are engaged in investigations relating to it.

This bulletin was prepared by Prof. W. J. Spillman, Agriculturist in Charge of the Office of Farm Management, and is in two parts. Part I is an outline of the science of farm management, which it is believed will be helpful to teachers in the agricultural colleges. Part II is an outline of the investigations conducted in the Office of Farm Management of this bureau. It discusses the principal problems under investigation and the investigational methods in use.

Respectfully,

B. T. GALLOWAY,
*Chief of Bureau.*

Hon. JAMES WILSON,
*Secretary of Agriculture.*

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# WHAT IS FARM MANAGEMENT?

## I.—THE SCIENCE OF FARM MANAGEMENT.

### INTRODUCTION.

Farm management treats of the business of farming from the following standpoints:

(1) Relative desirability of farming and other lines of business.
(2) Selection of the farm.
(3) Organization and equipment of the farm.
(4) Farm operation.

In the brief consideration that can be given the subject here no attempt will be made to treat of these subdivisions exhaustively; nothing further will be attempted than to make clear the nature of the subject, to present an outline of it, and to point out some of the services it can be made to render to the farmer. In the literature of the subject certain parts of farm management have received more adequate treatment than others, and these are presented here in brief outline. Other parts of the subject are newer and have not received adequate treatment in the literature of the subject, for which reason they are treated at greater length in this bulletin.

### FARMING AS AN OCCUPATION.

The relative desirability of farming as compared with other occupations is largely a personal matter and must be determined by the circumstances, tastes, and desires of the individual concerned.

Considered from the standpoint of stability, safety, and profitableness there are considerable differences between farming and other lines of business. It is for the most part made up of small independent units. Farming is, perhaps, more stable and less susceptible to serious interruption from disturbances in the financial world than any other business. On the other hand, it is perhaps more dependent on the elements than any other form of business. In addition, the average profits in farming are small.

Farming does not readily lend itself to corporation methods of conducting business and is therefore preeminently a business of individual rather than corporate enterprise. In fact, farmers as a class live so much to themselves and depend so little on each other in the conduct of their business that it is difficult to secure cooperation among them even when this cooperation would be highly advantageous to those concerned. Yet the hope of the future, that the farmer may be able to cope successfully with those who are in a sense organized against him or who are in position to take unfair advantage of him, lies in the possibility of developing cooperative effort, especially in the matter of buying and selling. This is more especially true in the case of selling perishable farm products, such as fruit and truck crops.

The numerous advantages and disadvantages of country life as compared with city life, which would be considered fully in a more extended treatise, can not be discussed in so brief an article as this must necessarily be.

## SELECTION OF THE FARM.

The selection of the farm is of special interest to young men who look upon farming as their life work, to those seeking a new location, and to those who contemplate moving from the city to the farm. But even to the man who already owns a farm the considerations involved in selecting a farm are of value because they are helpful in aiding him to determine the value of his own property and to judge the adequacy of the improvements on it.

This subdivision treats of all those factors that affect the desirability of a region as a general location for farming as well as those which affect the value of particular farms. It deals with the climate, the character of the soil, the availability of farm lands, transportation facilities, the social and educational conditions, the general healthfulness of the region and of the particular locality, the character and availability of farm labor, and similar questions of general or regional significance. It also deals with individual farms from the standpoint of all those features that affect their desirability and value, such as the fertility of the soil, the topography of the land, the character of the improvements, the distance to market, the distance to schools and churches, the arrangement of the fields, the location of the buildings, etc.

These questions will not be discussed at length here, since the purpose of this bulletin is to define the subject of farm management rather than to discuss fully its details.

## ORGANIZATION AND EQUIPMENT OF THE FARM.

The organization and equipment of the farm is the selecting of suitable enterprises as the basis of the farm business and of fitting them together into a satisfactory system of management. Ordinarily this means a system that will permit the maximum use of power, labor, and capital within the limits of the owner's available resources; that will require a minimum of equipment with the maximum use of that equipment; and that will so distribute the labor during the season that the farmer and his available labor, both of man and beast, will be profitably occupied at all times without being too much crowded at any one time. It also involves the determination of the character and extent of the equipment required for the satisfactory conduct of the business and the installation of this equipment.

### SELECTION OF ENTERPRISES, OR CHOOSING THE TYPE OF FARMING.

By a farm enterprise is meant any crop, type of live stock, manufacturing process, etc., which constitutes a part of the farm business. One of the most responsible tasks the farmer is called upon to perform is the selection of the enterprises to be conducted on his farm. On the wisdom of his choice depends very largely the financial success of the business.

Enterprises are not always chosen because of their immediate profitableness; for instance, a crop may be grown for its effect on the soil or because of some special value as a feed, but, generally speaking, the leading consideration concerning any contemplated enterprise is the prospect of its being profitable under existing conditions. The principal factor to be considered in determining whether an enterprise would be profitable in any given case is the experience of farmers generally in the region. This, however, is not an absolute criterion, for one man may succeed where another would fail. It is therefore necessary to consider the general principles that apply to the case.

As a rule those enterprises that are of large extent, such as corn, wheat, hay, dairying, hog raising, and the like, are less subject to wide fluctuations in prices than those less extensive, such as truck farming, hop culture, bean growing, potato culture, etc. It is seldom wise to base the business of a farm entirely on enterprises that are subject to violent fluctuations in prices.

Hops will illustrate this point. This is a small enterprise, taking the country as a whole, and there is not room on the markets for more than a small fraction of the hops that could be produced if all the land suited to this crop were devoted to it. Yet when prices are

good the crop is highly profitable. These conditions result in eras of high prices followed by periods of overproduction and consequent low prices. In order to bring a satisfactory profit to the grower hops should sell for about 10 cents a pound. The price has been as high as $1 a pound at times, especially following a long period of low prices that caused many growers to destroy their hopyards. These high prices induce new planting, frequently great overproduction, and thus bring about a drop in prices. Hops have sold for $1 a pound one year and 4 cents a pound a year or two later, which, of course, brought ruin to the growers.

The lesson to be drawn from this is that when such an enterprise is adopted it should not be allowed to represent too large a proportion of the farm business, but should be only one of several enterprises.

The mere fact that an enterprise is small, taking the country as a whole, does not necessarily render it undesirable. Location with reference to markets has much to do in determining this point. There are many products that either because of their quickly perishable nature or because of their bulkiness and relative cheapness can not well be sent to distant markets, at least not without great expense. This is particularly true of market milk and some kinds of vegetables and fruits. Hence it follows that these enterprises are much more important in the agriculture of regions near the great market centers than elsewhere. But even where climate, soil, and distance to market render an enterprise feasible there may be market conditions that would make the enterprise unprofitable. Thus a farm may be well suited to the production of market milk, yet combinations of city dealers may fix prices in such a way as to leave the farmer little profit. Again, a farm may have soil well adapted to truck farming and be so near to market that transportation charges are unimportant, yet it is doubtful whether this type of farming is ever to be recommended to small farmers who can neither sell their produce direct to retail merchants nor take advantage of a farmers' marketing organization. Where the grower of truck crops must depend for his sales on an unknown commission merchant in a distant city, who has every opportunity to defraud the farmer, and the farmer's business is so small that he can not afford to go to the city to see that his shipments are honestly sold and paid for, truck farming is generally not profitable. Such considerations as these must not be overlooked in determining what enterprises to adopt in any given case.

It may sometimes happen that a crop is more or less eminently adapted to a particular soil type of very limited extent, or at least is vastly superior when grown on a particular soil of which the available area is relatively small. In such cases an enterprise which

is small in extent and hence is subject to rather violent fluctuations in production and prices may form a much larger proportion of the business of a farm than would ordinarily be wise.

A case in point is tobacco in certain sections where a superior quality of product is grown. If the soil of a farm is such as to enable the farmer to grow a product greatly superior to the usual grades on the market and the area of similar soil is not large enough to overstock the market even if all of it were devoted to this crop, then it follows that even if there is an era of overproduction in the crop most of the product must come from land not capable of producing the best quality. The crop will have to be abandoned on such land before it is abandoned on the better soils, which will leave the markets to those who have suitable soil for the crop. Not only that, but even during eras of low prices the lowest prices will not apply to the best quality of the product, so that even when prices are at their lowest there generally will be some profit for those who produce the best quality.

The relation of agricultural enterprises to climatic conditions is so obvious as to need only the merest mention here.

Another important consideration in deciding whether an enterprise is desirable under given conditions is the cost of the necessary equipment. Many farmers, especially of the tenant class, do not keep live stock because of the expense involved in securing the necessary breeding stock and the buildings required for sheltering them. Not infrequently a farmer will be found who could find a good market for a few acres, say, of potatoes or cabbages, but who is unable to avail himself of this opportunity because of the rather expensive machinery required to produce these crops economically. These are questions that must be taken into consideration in recommending types of farming.

Closely related to cost of equipment is the amount of labor an enterprise will entail, as well as the time of year when this labor must be done. In many cases the farmer is limited in the amount of labor he can command, and an otherwise desirable enterprise may be unsuited to the conditions because it would require too much labor or labor of a kind to which the farmer is not adapted. It frequently happens that a crop may be very desirable for many reasons and yet not be satisfactory in a given case because it demands attention at the same time as some more important crop. This is probably one of the reasons why the cowpea crop has made no more headway as a separate farm crop in this country. It demands work simultaneously with corn, the most important of all our crops, and in the South interferes with the work on both corn and cotton, the two most important crops of that section. The same thing is true of soy beans.

Both of these valuable legumes have had some difficulty in finding a place in American agriculture and apparently mainly because when they are introduced on the farm they tend to crowd out more important crops that demand labor at the same time.

Sometimes crops which may ordinarily be very profitable are found to be well adapted to a given locality and even to fit well in cropping systems that give a very satisfactory distribution of labor, and yet the limited market for the product may render it unwise to develop the enterprise to the fullest extent of its possibilities. The bean crop in the upper Columbia River basin is a case in point, or at least may be. The crop succeeds well in certain portions of this area, does not interfere with the labor on the wheat crop, which is the principal agricultural enterprise of the region, and occupies summer-fallow land that would otherwise lie entirely idle during the bean-growing season. Hence, if beans were one of the standard crops of the country, representing an enterprise so large that an increase of a few hundred thousand acres would have very little effect on the relative output of the crop, it would be permissible to develop the bean industry on a large scale in this region, which seems to be so well adapted to it. But the fact is that the bean crop is a small one, and any large increase in its acreage would result in a relatively large increase in the total crop. This would seriously affect prices. For this reason the development of the bean industry in the section in question must be made only after a careful study of the area adapted to the crop and the possibilities of a satisfactory market for the product should the output increase considerably.

Finally, the effect of an enterprise on the fertility of the soil is sometimes a determining factor in its adoption. Thus, thousands of farmers maintain herds of stock which do not return market prices for the feed given them, but they do this because of the effect the manure has upon the yield of their crops. In very many cases this practice is justifiable. Suppose a farmer with no live stock except work animals could produce 35 bushels of corn per acre, while with a full complement of stock on his farm he could produce 80 bushels. Suppose he could sell his corn for 60 cents a bushel and that he can get 40 cents a bushel by feeding it; which practice, in the long run, is the most profitable? Thirty-five bushels at 60 cents is $21 per acre; 80 bushels at 40 cents is $32 per acre. Hence, under the conditions assumed, the keeping of live stock would bring $11 per acre more income than the system of selling corn on the market. This $11, however, is not all profit, for the interest on the investment in live stock and the labor cost of keeping the stock must come out of it.

Again, leguminous crops are very frequently grown because of their beneficial effect on the soil, even when some other crop might be temporarily more profitable. Thus, clover is regularly grown on hundreds of thousands of farms without direct profit but with much benefit to the land. Usually, however, the clover crop is directly profitable, but seldom so much so as corn, for instance. In a few localities the production of clover seed is quite profitable. In the South cowpeas are grown extensively as a catch crop in corn, simply for the effect on the soil. Alfalfa, the great leguminous crop of the West, is not only highly beneficial to the soil, but is frequently one of the most profitable crops the farmer can grow. It is, therefore, not surprising that in sections where this crop succeeds well it usually occupies a commanding place on the farm, much more so than clover does in its territory and vastly more so than do cowpeas in the South.

The factors which must be taken into consideration in determining the desirability of an enterprise in any given case may be summarized as follows:

(1) Profitableness, as determined by general and by local experience.

(2) The extent and distribution of the enterprise. This has much to do with the stability of the supply and demand.

(3) Location with reference to markets.

(4) Conditions existing in the market centers, especially combinations of dealers which control prices.

(5) Soil and climatic conditions.

(6) Cost of equipment required.

(7) Amount and character of labor required.

(8) Seasonal distribution of labor.

(9) Extent of a possible market for the product and the probable effect of a considerable increase in the supply on market prices.

(10) Effect of the enterprise on the fertility of the soil.

In an extended treatise on farm management each of the principal agricultural enterprises would be considered in detail from the standpoint of each of the foregoing factors.

## TECHNOLOGICAL PROCESSES ON THE FARM.

A full discussion of farm organization would involve the discussion of the use of technological processes on the farm, both as a means of filling in gaps in the labor schedule and as a means of securing enhanced prices for the products of the farm. The nature of these processes will necessarily vary with climatic conditions, as well as with the type of raw materials which may be produced on the farm or may be easily procurable for such processes. Some of the leading ones conducted on American farms and therefore worthy of consideration in this connection are the curing of meats, the

making of butter and cheese, and sirup making. In a treatise on farm management these processes would not be considered from the standpoint of methods of conducting them, but from the standpoint of their desirability under different conditions, the equipment and labor they require, the cost of equipment, and the financial results to be expected from them.

### LABOR REQUIREMENTS OF ENTERPRISES.

The farm-management view of a crop is quite different from the agronomic view. The agronomist, or crop specialist, considers a crop from the standpoint of its requirements as a living, growing thing. It is his work to learn what effect different methods of treatment will have on yield; in short, to learn how to manage the crop to produce the largest yield. He considers the rate of seeding, the depth of planting, methods of preparing the seed bed, fertilizer requirements, methods of tillage, methods of harvesting, and the like.

In studying farm organization, which is one of the leading phases of the subject of farm management, our interest in the crop relates to the amount and kinds of labor required in the management of the crop and the equipment necessary in performing that labor. In order to formulate a cropping system that will give an equitable distribution of labor during the season, we must know the following facts concerning each crop to be used in the system:

(1) The kind and number of operations required by the crop from the beginning of the seed-bed preparation to the marketing of the product.

(2) The crews (men, horses, and machinery) that may or should be used in performing these operations.

(3) The dates between which each operation may or must be performed.

(4) The amount of work each crew should perform in a day. This involves standards of farm labor for all possible kinds of farm work.

(5) The proportion of time at all seasons of the year that can be devoted to the kind of work to be done. This requires a knowledge of the average amount of time lost because of unfavorable weather, holidays, unavoidable delays, etc.

These five classes of data concerning a farm enterprise constitute the fundamental farm-management data concerning that enterprise. Until they are made available it will be impossible to work out, except by the slow and costly methods of experience, systems of farming that will give a satisfactory distribution of labor and which will give the farmer something profitable to do at all seasons of the year, while at the same time no part of the year will be so crowded with labor as to make it difficult to get the work done in its proper season. With such data it will be possible to formulate systems that will not only distribute the labor advantageously but will greatly reduce the number of work animals necessary to farm a given area. The aver-

age farm horse in the Northern States works on the average for the year only about three hours a day. Yet at certain seasons of the year he not only works 10 or 12 hours, but the farmer seldom has enough horses to do the required work. With a properly planned cropping system it will be possible to so distribute the horse labor as to secure twice the above amount of work per horse, thus reducing by one-half the number of horses required to farm a given area.

By distributing the work in this manner it will become possible to prevent a great deal of duplication in farm implements as well. Thus, on a farm where the system of management requires the plowing of the whole farm in the spring, only a few acres can be plowed with one plow, and there must be plows as well as horses and men enough to plow the whole farm in a short time. But if the work is so distributed that about half the land can be plowed in the fall, then one plow can be used on twice as many acres in a season as under the other system. This will reduce the number of plows required.

Thus the purely farm-management data concerning the management of a crop relate to the work the crop requires and to the relation this work bears to the work required by the other enterprises conducted on the farm, or which may be introduced to advantage. Agronomy is concerned with how to treat the crop in order to get it to thrive best; farm management is concerned with how to get the work done which the agronomist says should be done.

### CRITICAL PERIODS OF ENTERPRISES.

Most farm enterprises require more work at some seasons of the year than at others. The cotton crop, for instance, has two periods at which it demands an unusual amount of work—i. e., chopping out (thinning) and picking. A man can prepare the land, plant, and cultivate a much larger area than he can chop out or pick. It is customary in the cotton States for all the members of the grower's family who can handle a hoe or pick cotton, both light tasks suitable to women and children, to aid at these critical periods. Even with this help one man can still do all the other work on a much larger crop than an ordinary farm family can care for during the critical periods. It is clear that the limiting factor in the area of cotton a farmer can manage properly is the area he and his available labor can thin and pick. Where the available labor is limited to the members of the farmer's family, this area is so small in the case of the average family that a single horse can do all the horse labor required on the farm. This accounts for the general prevalence of 1-horse farming in the South. So long as southern agriculture is based as largely on cotton as it has usually been during the last generation, the 1-horse farm will be an economic necessity.

There is a better way, however, even for the cotton country. By the proper selection of enterprises the cotton grower may produce a large acreage of other crops, especially if he utilizes two horses, without cutting down the acreage of his cotton crop. But to do this it will be necessary to select enterprises that will not require much attention, if any, during cotton chopping or picking time. One of the big farm-management problems of the South is the formulation of systems of farming that will utilize the forces that now go to waste at seasons when the cotton crop does not completely employ the farmer's time and equipment.

The critical periods for the potato crop are planting and harvest. Corn is a crop that has no strictly critical period. It gives about the same amount of work at all times, from the beginning of plowing the seed bed to the last cultivation. Even at harvest time one man can gather all the corn he can grow, though it is customary to employ extra labor at this time. Generally speaking, farm enterprises have one or more periods when so much work is required that those periods determine the extent of the enterprise in any given case.

### SEASONAL DISTRIBUTION OF LABOR.

Farm-management surveys conducted by Cornell University and by the Office of Farm Management have shown that, within limits, the labor income of the farmer increases with the size of his farm, and, especially on small farms, with the diversity of the enterprises followed; that is, large farms are more profitable than small ones, and farms having several kinds of products to sell are more profitable than farms having only a few kinds to sell. The reason for both of these facts is probably the same, i. e., that a large farm even when devoted to a few of the leading farm enterprises and a small farm having a large number of enterprises will ordinarily give the farmer opportunity to find profitable employment for a greater portion of the year than a small farm with only a few enterprises. In both cases, also, the farmer has the opportunity to employ more labor, both of man and beast, as well as more capital.

One of the faults of American agriculture is the lack of systems of management that will keep the farmer properly busy at all times during the year. On cotton farms in the South there are, as we have already seen, just two really busy seasons, i. e., chopping time and picking time. The area of cotton that an ordinary farm family can thin in the spring and pick in the fall is so small that it does not keep one man well occupied the rest of the year.

In many sections corn and oats are the principal crops grown. Both of these crops cause much work in the early spring, and corn gives work until time for the oat harvest early in July. But after

the oats are harvested there is a period of a month or two when there is no field work to do. Examples of this kind could be multiplied indefinitely.

In almost no section of the country do the systems of farming employed furnish the farmer profitable employment during the winter. It is possible, by proper choice of enterprises and by properly gauging the magnitude of each enterprise, to organize the work of a farm in such a manner as to give profitable employment to the farmer and his available labor throughout at least the greater part of the year, certainly during the entire season when field work is feasible. Some such systems are given later in this bulletin.

While in most cases it is desirable to have systems of management designed to give profitable employment at all seasons, there are conditions under which the farmer is justified in ignoring this point. For instance, it may be possible to devote the major portion of the farm to some crop that is very much more profitable than any other crop that could be grown. In such cases, if the farmer can get all the labor he wants when he wants it, and is not compelled to support this labor when he has no use for it, a condition which is, of course, exceptional, he may be justified in growing as much of that crop as the exigencies of good soil management will allow.[1]

In some cases farmers are so situated that they can find profitable employment for their available labor in clearing land, quarrying stone, cutting and hauling cordwood or staves, etc., when they are not needed on the farm. Such men are fortunate, for in their cases one of the most difficult problems, that of formulating a system that will give profitable employment the year round, is solved in advance. But such cases are exceptional. Nearly all farmers are compelled to find employment on their own farms and on enterprises connected with the leading crops and types of live stock of the country. Since these standard enterprises tend to remain approximately equal so far as their profitableness is concerned, it follows that the larger the proportion of the year for which the system provides work the greater is the labor income.

## CROPPING SYSTEMS.

It is impossible here, for lack of space, to consider all the various cropping systems in vogue in different parts of the country, or even the principal ones of the leading agricultural sections, to say nothing of outlining systems that give full utilization of the farmer's time and equipment. A few systems will be considered merely for the purpose of illustration. We shall find in their relation to the dis-

[1] See the article entitled "Seasonal Distribution of Labor on the Farm" in the Yearbook of the Department of Agriculture for 1911 for further discussion of this point.

tribution of labor and the utilization of power an explanation of some of the more prominent anomalies of American agriculture.

We have already seen that the limiting factor in the area of cotton an average farmer can grow is the quantity the members of his family can pick. This is about seven bales. On ordinary uplands, where the yield is about one-third of a bale per acre, this means about 20 acres of cotton to the family. One horse can till this acreage, and as no other money crop is grown a farm of this size is usually a 1-horse farm. A few acres of corn are grown, but as there is only one horse and as the cotton tillage keeps him quite busy, the corn is poorly tilled and yields very little. Because the implements used are all 1-horse implements, the preparation of the seed bed for cotton, the planting, and the tilling keep the farmer busy from early in the spring until late in July. The picking then occupies the fall season quite completely. Thus, the one crop gives the farmer employment during nearly the entire season. This is one of the reasons that the single-crop system of cotton growing has persisted so tenaciously in the South; it gives employment pretty nearly as constantly as a well-planned system of farming would do, and thus enables the farmer to earn a living. The difficulty is that it does not utilize the full possibilities of the man and therefore gives him a poor living. When a man is following a 6-inch plow or a 12-inch sweep drawn by an 800-pound mule his time may be fully but not well utilized, and he is not working at his full earning capacity. What the cotton growers of the South need are systems of farming that will permit one man to employ the full power of two or, better, four horses throughout the season. This would greatly increase the earning capacity of the individual.

If the good farm lands now unused, mostly in second-growth timber, were devoted to such cropping systems the South could with its present working force grow approximately its present acreage of cotton and at the same time devote twice or three times this area to other crops. This would, of course, require a large increase in the number of work animals used as well as in implements, and this would call for much more capital than is now available to the farmers of that section. When the problems here briefly discussed have been worked out for the South and southern agriculture begins rapid expansion to its full possibilities, there will be great need of sources of agricultural credit so that the money may be had for that development.

In the Pacific Northwest there exists a peculiar system of agriculture which illustrates some of the principles here discussed. In certain sections the farmers grow little else than wheat. Unlike cotton, this crop has no critical period during which it requires a vast

amount of hand labor, but can be handled from start to finish almost entirely by horse or mechanical power.

In eastern Washington the limit to the area of this crop one man can grow is the acreage of land he can prepare for seeding. In the preparation of the land one man can easily utilize five or six horses, and we actually find this number commonly used by one man. All the implements are made as large as practicable. By a further ingenious device the season for preparing the land is lengthened. A given field bears a crop only once in two years. The farmer therefore has a long time in which to prepare the land. But this time is not as long as might be expected, because the winters in that section are too wet to permit much field work and the summers are so dry that the soil soon becomes too hard to plow. But by double disking the land very early in the spring, which can be done before it is dry enough to plow, a mulch is created which keeps the soil mellow till late in June. Thus, with 5-horse teams and a comparatively long season in which to do the plowing, a large area can be prepared by one man. In fact, the typical size for a one-man exclusive wheat farm in that section is about 320 acres, on which 160 acres of wheat are grown annually. Managed in this way, a wheat farm gives the farmer plenty of profitable work to do from early in the spring until nearly harvest time. Then the harvest season gives another long period of work. In that region the varieties of wheat grown will stand several weeks after they are ready to cut, so that the harvest season is greatly prolonged, and with the system of harvesting in vogue there is no trouble about getting all the wheat cut and thrashed that a farmer can grow. When harvest is over it is about time to begin sowing a new crop on the land that was plowed in the spring.

Thus, the system followed not only enables a man to utilize much power but it gives work through a considerable portion of the season. Under normal conditions this system of farming is quite profitable, and many farmers have grown quite wealthy in the wheat business. But there are dangers in the system, as the farmers very well know. Once for a period of three years the price of wheat was so low as to cause heavy losses. It is also probable that another generation of this type of farming would result in soil depletion to such an extent as to be disastrous.

This system does not use all the time and power one man could employ, and it leaves half the land idle every year. Methods of obviating these difficulties are now being worked out for certain localities, but it would require too much space to detail these here. Enough has been said to show why the farmers have clung so tenaciously to this system of farming in the face of urgent persua-

sion on the part of those who saw the defects but not the excellencies of the system.

The essential difference from an economic point of view between the prevailing methods of growing cotton in the South and wheat in the Palouse country is in the amount of horsepower one man can use in the two cases. The fact that machinery is not yet used for the most critical period of the cotton crop—the picking—and that the area of this crop a family can grow is therefore limited to what they can pick, and that this area is very small, renders it impossible on an exclusive cotton farm to profit by the possibility of using more power in plowing and in cultivation.

On the other hand, what was formerly the critical period for the wheat crop—the harvest—when this had to be performed by hand, is now not a limiting factor, for the farmer can get wheat harvested and thrashed from all the land he can plow, harrow, and sow. The real limit to the area of wheat one man can grow is the area he can plow in season. In this work he can readily use the power of five horses. For this reason he is able to farm a much larger area and secure a much larger income than the cotton grower.

The only way the cotton grower can get into the class of the wheat grower from the standpoint of income is by hiring a large amount of human labor at low wages for the two hand operations the cotton crop requires. As a result of this condition, most of the cotton is grown under a tenant system by poor people, while wheat is grown by the owner of the land himself, who is usually a well-to-do farmer. This applies, of course, only to those localities where the methods outlined are practiced.

A financial comparison of the two one-man systems of farming is shown in Table I.

TABLE I.—*Comparison of two one-man systems of single-crop farming.*

| Crop. | Charges. | | | Income. | |
|---|---|---|---|---|---|
| | Rent. | Interest and depreciation on equipment. | Total. | Gross.[1] | Labor.[1] |
| Cotton | [2] $72 | $15 | $87 | [3] $350 | $263 |
| Wheat | [4] 1,152 | 165 | 1,317 | [5] 2,880 | 1,563 |

[1] The farm expenses other than rent, depreciation, and interest on crop equipment are not here taken into account. Hence the labor income given is not the net income.

[2] Twenty acres at $3.60.

[3] Seven bales from 20 acres.

[4] Three hundred and twenty acres at $3.60.

[5] Four thousand eight hundred bushels (from 160 acres) at 60 cents.

Thus the possibility of using more power in the one case not only gives a much greater labor income, but the possibility of using more capital gives a correspondingly greater interest income.

Until the problems of thinning and picking cotton by machinery are solved the one-man farm must continue to bring only a bare living to the man who grows the cotton, provided he grows little else.

There are two alternatives for the cotton grower. In order to use more capital and more power and thus increase his income, he must either employ a great deal of cheap human labor or change to a system of farming that will permit him to use more power for those operations on the cotton crop which permit it, such as plowing and cultivating, and devote the time thus saved to other enterprises which also permit the use of a maximum of power. It is the province of the newly developing science of farm management to work out such systems for the cotton country.

While the two systems of farming just described are distinctly faulty and have been condemned by the best authorities, the fact is that, considered from the standpoint of labor distribution and the full utilization of a man's abilities, they are not much worse than the systems that prevail quite generally over the country. In fact, the system of wheat growing outlined utilizes a man's possibilities to far better advantage, and so long as the soil holds out and the price of wheat is satisfactory is far more profitable to the farmer than the systems prevailing in most parts of the country.

In general, even in the case of single-crop systems like those described, and more especially in the case of the more complex systems prevailing in the corn belt, the systems of farming that have been worked out by the cut-and-try method of experience will be found to give a first approximation to good seasonal distribution of labor and full utilization of equipment. This is necessarily so, for if it were not the case the farmers would long ago have been forced out of business.

The systems that have survived represent a sort of natural selection in which those that furnished the farmer a living survived, while the others disappeared. It is not exactly the survival of the fittest; it has been rather the elimination of the utterly unfit. Especially does the rotation of corn, wheat, and hay approach an ideal distribution of labor and use of equipment when the area of the farm happens to be just right and when the rotation is properly arranged. Thus a 6-year rotation of corn, corn, wheat,[1] wheat,[1] timothy and clover, timothy and clover gives a distribution of horse labor that is almost absolutely uniform from early in the spring until late in the fall. This keeps every needed horse busy and obviates the necessity of hiring extra horses as well. This system calls for extra man labor at wheat harvest, hay harvest, and in the corn harvest, but at other times the amount of man labor needed is just the same at all times.

[1] Fall sown. This rotation is adapted only to middle latitudes.

The area one man can farm with such a system is limited by the following factors:

(1) The area of corn land he can prepare for planting.
(2) The area of corn he can till.
(3) The area of wheat land he can prepare in the fall.

Fortunately, these three factors are equal. With two good horses one man can handle 40 acres of each of these projects. Hence, with this system he can farm 120 acres of arable land without extra labor except at harvest time. With four good horses it would seem that one man ought to farm 240 acres in this rotation, though this has never been even approximated in practice, so far as the writer knows. One farmer has been found who is actually farming the 120 acres that theoretically he should be able to farm with two horses.

The type of rotation found most generally on farms in the region to which this rotation is adapted is a first approximation to this one, which gives an ideal distribution of labor and reduces equipment to a minimum. These rotations are practically always some form of the general one of corn, small grain, timothy and clover. But since the farmers generally have not the data to work out the labor distribution of a system accurately—indeed, no one has this information sufficiently exact—the actual systems in vogue are only rough approximations of what they ought to be.

Another system of rotation that gives an even distribution of horse labor, so that a minimum number of horses can do the work of the farm, and that requires extra man labor only at harvest time, while at other times the regular help is kept reasonably busy at remunerative employment, is corn, corn, cowpeas (or soy beans) sown broadcast, wheat, wheat. With two good horses one man can manage 75 acres in this rotation; with four horses he should manage 150 acres. Reference is here made only to the field work. This last rotation would furnish cowpea hay, straw, and corn stover, all of which could be used to advantage as feed for live stock, especially dairy cows. A good herd of cows furnishes labor equally distributed throughout the year, so that a dairy farm with the rotation mentioned would represent an excellent system from the standpoint of the distribution of labor and economy in equipment.

Generally speaking, any cropping system which has stood the test of time and prevails pretty generally over an important agricultural region will be found to give at least an approximation to uniform distribution of labor with minimum equipment. But when the farmers in a region where rather poor farming is done attempt to break away from prevailing practice and begin to invent new rotations, under the impression that rotation farming is an improve-

ment over the prevailing methods in their locality, the crude rotations often resulting are frequently very far from satisfactory from the standpoint of equipment and labor distribution. It not infrequently occurs in such cases that the new system necessitates the plowing of all the land on the farm in the early spring. To do this requires an army of horses and plows as well as plowmen. The plowmen can be hired temporarily, but as a rule the farmer must own the plows and horses. He must also be supplied with harrows, cultivators, etc., to correspond. After the rush of spring work is over nearly all of the horses and equipment stand idle for most of the season. Such systems do not last long and never become general in a region.

Enough has been said here to show that the work of reorganizing the agriculture of a region that for any reason is in an unsatisfactory condition is a task worthy of the best minds in the country. The farmers, unaided by the scientific investigation of the subject, will finally reach an approximate solution of the problem, but the process will be so slow that by the time this approximation is reached changed economic conditions may have rendered the new systems worked out by the farmers unsuited to the then existing conditions. Hence this is the work of the agricultural scientist, and the investigator is confronted by no more important or difficult task than that of farm reorganization. It is practically a virgin field. The fundamental data on which such work must be based are not yet at hand. The present task of the farm-management investigator is to secure these data.

### THE AREA ONE MAN CAN FARM.

Of the factors that determine the size of the one-man farm the most important is the enterprises adopted, and, as we have just seen, it is the critical periods of these enterprises that are important in this respect. But the extent of a single enterprise that one man can manage depends on a number of factors, the most important being the character of equipment used.

In most sections of the country it is customary to employ temporary labor during critical periods, especially at harvest time. With cropping systems that require only extra man labor at critical periods and no extra horse labor, and where it is possible to arrange such systems, it is usually quite feasible to increase the acreage farmed to the largest area that the available horse labor will provide for, since it is usually possible to secure extra man labor, even when extra horse labor can not be had. Where extra man labor can be had at harvest time, then the area farmed will depend on the number of horses one man can utilize. In many cases it is practical to do almost all the field work with 4-horse teams. To do so, of course, doubles the area one man using a 2-horse team can farm.

The length of the season during which field work can be done also influences the area a given force can farm. In sections where the field work can begin in the very early spring, as it can all over the South, one team can prepare more land for seeding than in sections where the spring season is short, as it is in the northern tier of States. On the other hand, the heat during summer in the Southern States tends to reduce the acreage that can be tilled by a team.

The character of the soil also affects the area a team can plow and till. On light sandy soils a team can cover more ground at most operations than on heavy clay soils. The presence of stones, as in many New England fields, and the presence of roots and stumps, as in newly cleared land, also reduce the area that can be farmed. On irrigated land the area a given force can farm is smaller than on nonirrigated, for the irrigating takes time, and the presence of ditches in the fields, causing frequent turning on short rows, reduces the area that can be covered in a day.

Uniformity of equipment is another factor often overlooked. On a 4-horse farm it is a waste of time to have part of the field implements of a size adapted to two horses and another part to three. By using only 4-horse implements in so far as this is practicable the time of one man is frequently saved, or if only one man is available the constant use of 4-horse implements greatly increases his efficiency. One of the problems to be worked out by farm-management investigators is the practicability of using implements of uniform size for field work, especially the sizes that utilize the largest possible amount of power, or at least all the available power on the farm.

### RELATION OF MAGNITUDE OF BUSINESS TO PROFIT.

Profit in farming depends not only on the intrinsic profitableness of the enterprises adopted, but also to a great extent on the amount of power employed and the amount of capital invested. If there is profit in an enterprise conducted on a small scale, there ought to be more profit in it when conducted on a larger scale. A system of farming that limits the farmer to the use of one horse gives less opportunity for a large income than one that permits one man to use four or five horses to advantage. A comparison has already been given of two types of farming which illustrate this. Any system of farming that limits the worker largely to what he can do with his hands, without the aid of horse or mechanical power of some kind, will, as a rule, bring small returns, and those who follow it will have incomes little, if any, larger than ordinary wages. At least in the case of crop products grown for sale the amount of horsepower the grower can utilize to advantage is an index to the labor income a man can make single handed—i. e., on a one-man farm.

In order to secure the larger use of power and capital either of two methods may be pursued. In localities near the large market centers and on some farms near smaller centers the more intensive types of farming may be instituted, in which the amount of work to be done on a given area is large and in which much capital may be advantageously employed. In localities where such intensive enterprises are not appropriate because of lack of a suitable market for the products the best means for the farmer to employ to put himself in a position to use more capital and employ more power is to increase the size of his holdings either by purchase or by renting. Some of the most prosperous farmers in the country are farming rented land. These are men whose capital is too small to permit them to own large tracts of land, and they wisely lease as large an area as their capital will permit them to equip and farm properly, thereby securing the possibility of using much power with comparatively little capital.

The size of the farm should, if possible, be large enough to permit the farmer to use as much power as his capital renders possible, whatever the type of farming adopted.

### THE NORMAL SIZE OF FARMS.

In those sections of country where the farmers must in the main depend on the ordinary field crops and the common types of live stock the normal size of the farms may be assumed to be such as to give full employment to the number of horses worked in one team to the best advantage. As 2-horse teams are much more commonly used than any other in most parts of the corn belt, it would naturally be expected that the 2-horse farm, or rather the farm that would keep one 2-horse team busy with the field work, would be the most practicable size for which to formulate a satisfactory working plan. It must be remembered that the average farm is not very well planned, and that for this reason one team does not ordinarily do the field work for areas as large as those above shown to be possible with a well-planned system.

In this connection the statistics concerning the relative numbers of farms of different sizes as given in recent data of the Bureau of the Census are of great interest. We should expect to find that those sizes of farms would be most frequent that permit fairly good organization with the least difficulty. This means, in the corn belt, the 2-horse farm. Farms smaller than the full capacity of two horses would not give full employment of labor and equipment when ordinary field crops are grown, and in the corn belt generally these are the leading enterprises of the average farm. Hence, these smaller farms would not be so profitable, or rather it would be more difficult

to make them profitable, and the number of the smaller farms would tend to decrease while the farms of a size adapted to easy organization along economic lines would increase in number. The facts as to this point are given in Table II for some of the leading corn-belt States.

TABLE II.—*Change in sizes of farms in the corn belt.*

[Sizes which are increasing in number are marked plus (+), those decreasing in number are marked minus (−), and those stationary are marked with a point (⊙).]

| States. | Sizes of farms (acres). | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 3 to 9 | 10 to 19 | 20 to 49 | 50 to 99 | 100 to 174 | 175 to 259 | 260 to 499 | 500 to 999 | 1,000 |
| Indiana | + | + | − | − | + | + | + | − | ⊙ |
| Illinois | + | + | − | − | + | + | + | − | ⊙ |
| Iowa | + | + | − | − | + | + | + | − | ⊙ |
| Wisconsin | + | + | − | − | + | + | + | − | ⊙ |
| Michigan | + | + | − | + | + | + | + | ⊙ | ⊙ |
| Ohio | + | + | − | ⊙ | + | + | − | ⊙ | − |

The table shows that the two smaller sizes of farms are increasing in numbers in all six of the States specified. These small farms are undoubtedly mostly truck and fruit farms and hence are organized in an entirely different way from those devoted to the standard field crops. These small farms are not as numerous in this division of States as they are farther east, but are increasing practically everywhere to some extent, to meet the growing demands of the cities for fruit and vegetables.

The next two sizes of farms are decreasing in numbers. They are too large for gardens and not large enough for farms under the average conditions prevailing in these States. In the older States to the east these two sizes are on the increase for the reason that there the problem of suitable organization of these intermediate-sized farms has been better worked out.

The next three sizes, including farms of 100 to 500 acres, are all increasing in these corn-belt States. This is because their size lends itself to easy organization on economic lines with the enterprises that are best adapted to that region.

Farms larger than 500 acres are either not increasing in numbers or are actually decreasing. These figures well illustrate the fact that farms either smaller or larger than those we have here called normal-sized farms are difficult to organize satisfactorily and consequently have not generally been so successful as the better organized normal-sized farms.

The acreages in Table II are for the whole farm, including a good deal of land not actually farmed. The census data do not give the area of land actually under cultivation on these farms, but it is

known to be somewhere near two-thirds of the areas given in that table.

In this region of corn, wheat (or oats), and timothy and clover the 125 to 160 acre farm is not only increasing in numbers more rapidly than any other size, but it already constitutes by far the most numerous group in most of these States.

The problem of the farm of intermediate size (20 to 99 acres) is an exceedingly interesting one. When such a farm, with, say 40 to 50 acres of arable land, is devoted to the ordinary farm crops, it utilizes neither the farmer's time nor his equipment to its full capacity. In order to make such farms profitable it is necessary either to add some such industry as dairying or to substitute for part of the field crops more intensively worked crops, such as fruit and vegetables. These types of farming find their opportunity largely in the vicinity of large cities; hence, we naturally find farms of this size in the older States near the great market centers.

### REDUCING THE COST OF PRODUCTION.

The full utilization of equipment is an important means of reducing the cost of production, since it reduces the amount of equipment necessary. The average farm horse in the Northern States works only three hours a day. This is because the system of management on the average farm is so poorly planned that at certain times the work is very heavy, while at other times there is nothing to do. It is necessary to keep horses enough to meet the needs of the farm when the work is heaviest, but at other times these horses are idle. The average cost of horse labor on the farm under these conditions is about 10 cents an hour. With a well-planned cropping system that distributes the farm labor equally throughout the season it is possible to get six hours' labor per day out of the horses. When this is done the cost of horse labor per hour is reduced to 5 cents.

Many a $12 plow is used to plow not more than 10 acres a year. At this rate the cost per acre for the use of the plow is about 18 cents. When the same plow is used to plow 40 acres a year the plow cost per acre is reduced to about 5 cents, or less than one-third what it is when the plow is used on only 10 acres. Approximately the same thing is true of all other items of equipment. On poorly planned farms the equipment cost is excessive because each item of equipment is used to less than its capacity. For the reason that the equipment must be sufficient to do a great deal of work in rush periods the amount of equipment on poorly managed farms must be much larger than on well-managed farms where there are no rush seasons. On the latter type of farms the work is well distributed, so that no great amount of it must be done at the same time, thus making possible a minimum of equipment.

These are all arguments for well-planned systems of farming. One of the greatest strictly farm-management problems is that of working out such systems in all sections of the country for farms of all sizes and types.

### THE FARM GEOGRAPHY.[1]

Another chapter under the general heading "Organization and equipment of the farm" relates to the layout of the farm, or its subdivision into fields, pastures, wood lot, farmstead, etc. No extended discussion of this phase of the subject will be given here, since the title of this chapter is self-explanatory. Reference to it is made here to show its place in a logical arrangement of the subject matter of farm management: The subdivision of the farm into fields is determined largely by the type of farming and the particular enterprises constituting the basis of the farm business. The topography of the land, especially where it is more or less hilly, is also a factor. The size and shape of the farm also help to determine the most suitable arrangement of the fields.

### THE FARMSTEAD.

The location of the farmstead, i. e., the group of farm buildings and the yards, lots, garden plat, and kitchen orchard that naturally accompany them, depends on the size of the farm, the location of near-by roadways, the topography of the land, and the prevailing direction of the wind. Since this bulletin is not a treatise on farm management, but rather an outline of that subject, and since the pertinence of this part of the subject is easily apprehended, no further discussion will be given here of the factors determining the location of the farmstead or of the plan of arrangement of its various parts.

### FARM EQUIPMENT.

#### FACTORS OF PRODUCTION IN AGRICULTURE.

The factors of production are classified by economists as land, labor, and capital. This classification is not satisfactory in the consideration of agricultural production for the reason that land itself represents the larger part of the farmer's investment and hence must be considered as a major item of his capital. Furthermore, in practice a different classification of the equipment necessary in agricultural production is well established. For purposes of taxation and in the buying and selling of farms it is customary in this

[1] Many valuable suggestions relating to this and other farm-management subjects may be found in Bulletin 236 of the Bureau of Plant Industry, entitled "Farm Management: Organization of Research and Teaching," by W. M. Hays, Andrew Boss, A. D. Wilson, and Thomas P. Cooper. 1912.

country to divide farm property into real estate and personal property. It will therefore be most satisfactory in discussing the subject to follow the classification of farm property already in general use. Accordingly, we may classify the factors of production into the following three general groups, with their subdivisions as indicated:

- I. Real estate, or the land and its permanent improvements.
  - Land.
  - Dwellings.
  - Other farm buildings.
  - Fences.
  - Drainage systems.
  - Water supply.
- II. Personal property, or the working capital.
  - Live inventory.
    - Work animals.
    - Other live stock.
  - Dead inventory.[1]
    - Implements and machinery.
    - Circulating capital.
      - Supplies and stores, such as feed, seed, fertilizers, unmarketed stock and crop products, fuel, etc.
      - Cash (or credit) used for current expenses.
- III. Labor.

Of these factors, land is properly considered under the second subdivision of the subject of farm management, i. e., "Selection of the farm." The remaining factors all belong properly under "Farm equipment," which is logically a part of the subject of farm organization. No attempt will be made in this brief presentation of an outline of the general subject of farm management to discuss each of these factors in detail. A brief discussion of the cost of farm dwellings is given merely to illustrate the general method of attacking problems relating to farm equipment.

### COST OF THE FARM DWELLING.

How much money can the farmer afford to put into his dwelling? At first thought this question seems to admit of no definite answer because of the number of factors entering into the case, but it does admit of a perfectly definite answer, as will be seen.

The average cost of farm dwellings is controlled by two opposing forces. One of these is the pride of the farmer and his family and the natural and commendable desire for the comforts of life. This force tends to raise the cost of the dwelling. On the other hand, the farm income must suffice not only to defray the expenses of running the farm, but also the living expenses of the farm family.[2] The farm income must also, in the long run, build the dwelling. If

[1] "Dead" is used in the sense of inanimate. This is the term always used in German textbooks on farm management.

[2] Cases in which the family has other sources of income are not here considered

too much money is expended in erecting a dwelling, then the sum available for defraying the expenses of the farm and the farm family will be reduced to the point of being inadequate. The exigencies of meeting farm and living expenses therefore represent a counter force which tends to lower the cost of the dwelling. In the study of farm equipment, instances have been found in which the farmer had expended so large a sum on his house that he was seriously handicapped in the management of his farm because he could not afford to buy much-needed implements and machinery.

In the long run, i. e., on the average of a large number of cases, the point of equilibrium between these two forces will represent the proper cost of the farm dwelling, or rather a cost that to exceed would be unwise. Studies of this subject have been made in several parts of the country and the results have always been the same. The average cost of the farm dwelling is equal to the annual sum available for the living of the farm family, including that portion of the living represented by supplies obtained from the farm; in other words, it is equal to the net farm income for one year. There are probably sections of the country where for special reasons, such as depreciation of farm values or the decadence of agriculture, this rule does not hold, but it will probably be found to hold quite generally where agriculture is in a stable condition and where farmers generally have no other source of income than their farms.

Most of the other classes of farm equipment lend themselves to study in the same manner as do farm dwellings. The Office of Farm Management is now devoting a great deal of time to such studies, and the results should be of much value to farmers.

In the matter of farm labor, which is listed as one of the factors of production, the discussion of the amount of labor needed under different conditions in farming belongs properly here under farm organization. The management of labor is treated later in connection with farm operation.

## FARM ADMINISTRATION AND OPERATION.

### SYSTEMS OF OPERATION.

The first question to be decided in undertaking the administration of a farm is the system of operation to be adopted. The principal systems are:

(1) Proprietary system—
Operation by the owner and his family, with or without additional hired labor.

(2) Managerial system—
Operation by hired labor managed by the owner or a hired manager.

(3) Tenant system, with or without supervision—
Share tenants.
Cash tenants.

(4) A combination of two or more of the above systems.

In rural economics these various systems of operation are considered from the standpoint of the community or the State. The effect of each system on the character of citizenship and the general economic effect of the wide adoption of any system would be considered by the economist. In farm management we are interested in these systems from the standpoint of their practicability under given conditions and from the standpoint of their effect on the income of the owner of the farm. This includes their effect on the fertility of the soil, since this is an important factor in making the farm profitable. From the viewpoint of the farm manager the question is, What system of operation is most practicable under my conditions, which will give the largest net income, and what effect will the system have on the future yielding power of the soil?

### TENANT FARMING.

The most important feature of tenant farming from the farm-management viewpoint is the character of the contract between landlord and tenant. This is a very real problem to every one who rents land, either as owner or as tenant. The owner naturally wants all he can get for the use of his land and its improvements; the tenant just as naturally wants all he can get for his labor. The one great fundamental point on which all other details of the contract hinge is the proportion of the income of the business that should go as remuneration to labor and the proportion that should go as interest and depreciation on the invested capital. When this point is once determined it is an easy task to work out the remaining details, no matter what proportion of the working capital is furnished by landlord and tenant, respectively.

The proportion of the farm income that should go to labor will vary with the type of farming and with the fertility of the soil. This point is now under investigation by the Office of Farm Management, and it begins to appear that it will be possible to arrive at a few general principles that have very wide application and that will furnish a satisfactory solution for this vexed problem.

Aside from the division of income between labor and capital, the most important feature of the contract is the length of tenure for which it provides, though this is not usually considered as important as it really is. On this point depends very largely the effect of tenant farming on the fertility of the soil. With the usual form of lease contract the short-term tenant has no financial interest in what the farm may be able to produce after his lease expires. He is interested in getting out of the land all it will produce now, and does not care very much whether the soil is left in better or in worse condition than before. On the other hand, the long-term tenant

has an interest in the future yielding power of the soil. Short-term tenantry is highly undesirable from every point of view. This difficulty might be obviated, as it now is in England under the Agricultural Holdings Act, according to which a tenant on giving up a holding must be remunerated for any unexhausted improvements he may have made during the life of his lease, when these improvements have been made with the consent of the landlord.

Whether the contract between the landlord and the tenant shall be reduced to writing or shall merely consist of a verbal agreement is a question to be determined by the circumstances of each individual case. In some cases one method is best and in other cases the other. Space will not permit detailed discussion of this point.

It is assumed that the landlord shall furnish the land with the necessary permanent improvements and that the tenant shall furnish the labor. Aside from this, the principal points to be covered in a lease contract are as follows:

Items of working capital (supplies and movable equipment, including both live and dead inventory) to be furnished by each party.

Share of each party in the income of the farm or the amount of rent to be paid and the conditions of payment.

Items relating to soil management, including restrictions as to the cropping system to be used, the amount and kind of live stock to be kept, and the method of utilizing crop products.

Repairs of permanent equipment.

Length of tenure.

Tenant's privileges, such as keeping cows, pigs, and poultry, raising garden truck, and the use of supplies from the farm, including fuel.

Amount of supervision by the owner.

The general method of investigating this whole problem is that outlined in treating of the farm dwelling. It consists of a careful study of actual contracts all over the country, with special attention to the satisfactoriness of the various details, both to landlord and to tenant. A contract that enables the landlord to secure and keep a desirable class of tenants is taken to be satisfactory from the standpoint of the tenant; one that does not satisfy good tenants and under which they decline to remain after having had experience with it is considered unsatisfactory.

The cost and character of tenant houses, as well as their location with reference to the main dwelling, are subjects of some importance in farm operation and would receive attention in a treatise on farm management.

While it seems probable that tenant farming will increase as the value of farm land rises in this country, it is hoped that the work of the agricultural scientist may serve in some measure to counteract this tendency.

### HIRED LABOR.

The subject of hired labor as a part of the general subject of farm management takes up such questions as the supply of farm labor and the sources of this supply; wages and the methods of paying them, both to regular employees and to temporary day laborers; profit sharing; housing and boarding laborers; the laborer's privileges, such as the use of horses and vehicles, holidays, and trips to town, access to papers and books, and the social status and welfare of farm laborers from the standpoint of securing continued service from desirable laborers.

In the management of labor it is important that the manager have accurate knowledge of the standards of farm labor. If both manager and laborer understand this matter the management of labor is greatly simplified. Hence, in the management of labor it is well not only for the manager to inform himself on this subject but to make use of such data on the subject as are available as a means of educating the laborers he directs concerning what may fairly be expected of them. No one has a moral right to demand that the laborers under his direction shall work at a rate that would impair the working power of the laborer, but with this limitation the manager has a right to expect the best service the laborer can give.

### THE WORK SCHEDULE.

On a farm that has a definite cropping system, and in fact on any farm as soon as the plans for the season are definitely made, it is possible to make out at least a rough schedule of the work to be done during each month of the coming season. A very good plan is to divide each month into three periods, the first and second periods being 10 days each and the third the remainder of the month, which will make the third period 8, 10, or 11 days according to the length of the month. A chart can then be made having the dates in the left-hand column and the various crops or other enterprises for the headings of the remaining columns. Under each heading may be inserted in each 10-day period the work to be done on that particular enterprise during that period. It will, of course, not be possible, on account of the vagaries of the weather, to follow such a schedule blindly, but at the same time the schedule will be of great service in keeping track of the farm work. It is especially helpful as a means of foreseeing what equipment as well as what teams and men will be needed at particular times and this enables the manager to be prepared for work at the time it should be done.

Such a schedule is also helpful in the management of labor, especially of those who are inclined to shirk. If the schedule is based

on generally recognized standards of farm labor the laborer who fails to keep up with it is thus shown to be not doing efficient work.

It is also a good plan in connection with the work schedule, or even where no definite schedule is maintained for the ordinary field work, to keep on hand a list of things to be done at times when, on account of the weather, the field work is interrupted.

### CARE AND UPKEEP OF EQUIPMENT.

This part of the subject deals with such questions as keeping implements and machinery in repair and protecting them from the weather; the importance of having implements in order when the necessity for using them arises, instead of waiting until they are needed, and thus causing delay in their use; methods of keeping track of the supplies and the importance of having things on hand when needed, instead of having to stop work and waste time in going to town to get them; the losses occurring from careless handling of small tools and minor items of equipment, and methods of preventing such losses; the repair of farm buildings and their protection from fire; the importance of keeping drainage systems in repair; the principal difficulties that arise in connection with such systems and how to avoid or meet them; and the management of the water supply.

### FARM BOOKKEEPING.

The keeping of records of the farm work and business transactions is a very important part of farm administration. It is true that many farmers, even successful ones, do not keep any formal records, but this does not mean that they know nothing of the status of their business. When the business is not extensive or complex most farmers are able to carry the details in their heads sufficiently well to answer practical purposes. But when the business is large and complex, and especially when it involves a good many running accounts with parties with whom business is transacted, more or less formal record making becomes quite essential.

The leading classes of farm records, each of which would receive more or less consideration in a treatise on farm management, are the inventory, the financial accounts, the labor records, the performance records (such as milk records of individual cows, etc.), the feeding records, cost accounting, the record of supplies, the weather record, and the breeding records.

### PURCHASING SUPPLIES.

There are a few general considerations relating to the purchase of supplies and farm necessities that should be set down in a treatise on farm management. Some of these are the advisability of buying for

cash, the saving by buying in quantity, the value of promptness in meeting obligations, etc. In a mere outline of farm management it is unnecessary to enter into details in the discussion of these considerations.

### MARKETING PRODUCTS.

This is another subject that requires no extended mention in an outline of the subject of farm management, but should receive due consideration in a complete treatise on the subject. The necessity of putting up in an attractive manner any farm product that is to be sold directly to retail customers in the form in which it leaves the farmer's hands is so obvious that it ought not to need discussion, yet when one goes to market and sees unsorted and unattractive apples and potatoes exposed for sale beside the products from farms that send only attractive wares to the market, it seems that farmers have not yet generally learned this lesson. The unwisdom of trying to market perishable farm products, such as the softer fruits and truck crops, through unknown and unrecommended commission merchants in distant cities, who have every chance to practice fraud without let or hindrance, ought also to be so self-evident as to prevent anyone from relying on such methods of marketing; but the facts indicate that many have not learned this lesson, and some farmers apparently need to have the lesson repeatedly brought to their attention.

### STORAGE AND CARE OF FARM PRODUCTS AND SUPPLIES.

The depredations of insects and vermin on stored farm products in some sections are serious. Methods of preventing these depredations are of importance to the farm manager. Losses from exposure to the weather, especially in the case of such products as hay and fodder, are also subjects to be considered in discussing farm operation.

### CROP AND SOIL MANAGEMENT (APPLIED AGRONOMY).

The difference between the farm-management point of view and that of agronomy, relating to crop management, has already been pointed out. Farm management includes the application of the principles of agronomy in business. It also includes the application in practice of the principles of soil management, if, indeed, soil management is not to be considered simply a phase of crop management.

In actual practice it is frequently necessary to depart from the teachings of the agronomist, for the reason that to give each crop the care which the agronomist has shown to be desirable from the standpoint of the individual crops is not always feasible. Thus, it may be desirable to use both oats and corn in a rotation, in which to give the oats the best possible opportunity is incompatible with the

interests of the more valuable corn crop. There is little doubt that on the average oats will give better yields if the soil is plowed and put in excellent condition before the oats are sown. But to do this would greatly reduce the area of land that could be made ready for corn, since these two crops compete with each other for labor at the same season of the year. But if the oats are disked in on corn stubble without any previous preparation of the land, experience has shown that they do fairly well in some sections, and, since this can be done before the soil is in condition to plow, the full quota of oats can by this means be sown in the rotation without interfering with the preparation of the soil for corn. In farm management, therefore, we are not only interested in knowing what are the best methods of crop and soil management from the standpoint of securing maximum yields, but also what the result will be when departures must be made from the practice that would give maximum yields.

The maintenance of soil fertility is one of the most important problems confronting the farmer, at least in the older farming regions, and will ultimately be everywhere. We know very well that plenty of barnyard manure will build up infertile soil and maintain fertility in an already rich soil. But not every system of farming provides sufficient manure for this purpose. When manure is not available or is available in insufficient quantity provision must be made in most sections for some other means of keeping up yields. These other methods are much less well understood than the method of using manure. Provision can usually be made for supplying humus by growing catch crops at various points in the rotation practiced and by plowing under as much as possible of the refuse of the crops grown, especially the stubble of perennial hay crops. But this alone generally will not suffice, so that in default of abundant manure it is usually necessary, except in the more newly settled regions, to resort to the use of commercial fertilizers. It is an interesting question which the next generation of farmers may have to face, What will take the place of commercial fertilizers when the supply of phosphates and potash salts is exhausted?

One of the very important farm-management studies is to work out the relation between all kinds of practices to the maintenance of soil fertility. This problem is amenable to study by the experimental method, but the study of farm practice where applicable is not only cheaper and quicker but rightly conducted is much more accurate than the ordinary field-plat experimentation because of the much greater mass of data and the greater certainty that the results obtained will be applicable to actual farm conditions. This study should include the farm methods of managing manures as well as farm practice in the use of catch crops and of commercial fertilizers.

LIVE-STOCK MANAGEMENT (APPLIED ANIMAL HUSBANDRY).

Animal husbandry bears the same relation to farm management as does agronomy. In farm management we are interested in the application in practice of the principles of animal husbandry. Farm-management investigations do not properly include experimental work in either agronomy or animal husbandry, but they do include farm-practice investigations in both these subjects. It is one thing to discover a scientific fact in the laboratory and a very different thing to work out its application in practice. It is the latter phase of these two sciences that is of direct interest in farm management, and this phase can only be studied by the actual investigation of farm practice.

In farm management both crop and live-stock management are considered especially from the standpoint of complete systems and the bearing these systems may have on the remainder of the farm work.

STUDY OF SUCCESSFUL FARMS.

For the reason that many principles of farm management can only be studied in farm practice, the careful farm student or manager will study those that are distinctly successful. The student will learn much that can not well be set down in books and formal lectures, and the farm manager will find in the experience of others the solution of many problems that arise in practice that are never thought of in the classroom.

It is difficult to formulate definite plans for the study of actual farms. No two farms are alike, and a set of blank forms intended to bring out the salient points in the management of a particular farm will seldom suffice for another farm. Such studies should begin by getting a general view of the system of management in vogue on the farm. A very good plan of procedure is to get first a statement of the cropping system, including the acreage and yield of each crop usually grown, the rotation practiced, if any, and the use made of each crop. Then may follow a statement of the system of management of each crop, including complete details regarding the use of manures and fertilizers, the dates of plowing and seeding, the number of cultivations, etc., for each crop. Next may follow similar treatment of each type of live stock on the farm. After this, if any technological processes are followed, a complete account of them should be obtained. In obtaining an account of any enterprise the aim should be to secure a statement of every operation performed, the season of the year when it is performed, the amount of work it requires, and the equipment used in this work, including the number of men and horses and the kind and sizes of implements used. When departures from ordinary practice are met with it is always well to learn the owner's reasons for such departures, for this may lead to

the discovery of something of value in farm practice. Finally, a statement of the equipment of the farm as a whole should be obtained; also as accurate an account as possible of the annual expenses and receipts by enterprises. The blanks used by the Office of Farm Management or those used by Cornell University in making detailed farm-management surveys will be found very useful in studies of this kind, but they do not cover all the points that should be covered in making a thorough study of a successful farm for the purpose of learning from it all the lessons it has to teach. It is not possible in a farm-management survey to study each farm in such detail as the best farms justify.

### MANAGERIAL EFFICIENCY.

The final chapter of a treatise on farm management may well relate to the training and the personal characteristics that contribute to managerial efficiency. The corporate principle in business has been successfully applied everywhere except in agriculture. Generally speaking, large agricultural undertakings have not been successful, principally because suitable managers have not been available. Managers have been lacking partly because the principles of farm management have not been worked out and definitely stated, and the business is too complex for the average man to become a successful manager of a large undertaking simply through experience alone. When these principles are once clearly stated, there seems to be no reason why large farms should not be even more successful, financially, than small ones. Whether it is desirable from the standpoint of national economy for the small farm to give place to the large one is a question of rural economics and does not directly concern the science of farm management. Such changes are controlled by economic forces that work in spite of our attempts to counteract them. If large agricultural undertakings could be made as successful as those of moderate size are now sometimes made, there is every reason to believe that corporate agriculture would assume an important rôle in this country, whether or not it is desirable that this should be the case.

# II.—THE WORK OF THE OFFICE OF FARM MANAGEMENT.

## INTRODUCTION.

Science is sometimes defined as knowledge methodically formulated and arranged in a rational system, or, to express it more briefly, classified knowledge. In Part I of this bulletin the attempt has been made to present an outline of the science of farm management, in so far as the knowledge of the principles of this science is available, and to point out the principal deficiencies in this knowledge. Farm management is a new science and the facts in this field of knowledge are as yet imperfectly known. Hence the urgency of farm-management investigations.

In organizing scientific research we may divide the branch of science under investigation into its logical subdivisions and assign investigators to each of these subdivisions, or we may organize it on the basis of methods of investigation. In the organization of the research work of the Office of Farm Management both of these methods are recognized. In the main, the subdivision of the work is based on methods of investigation, but in the various sections of the office the work is to some extent divided along the lines of the subject matter investigated. In practically all efficient organizations for scientific research this dual type of organization exists, as it does to a marked degree in the general organization of the Bureau of Plant Industry, of which the Office of Farm Management is a part.

The object of Part II of this bulletin is to present an outline of the organization and work of the Office of Farm Management, with sufficient discussion to make clear the methods of investigation followed and the purposes to be attained.

It should be stated that the Office of Farm Management developed out of the old Office of Grass and Forage-Plant Investigations. Later a new office under the latter title was organized and most of the work relating to grasses and forage plants was transferred to this new office. There were, however, a few lines of work on these crops which for various reasons were left in the Office of Farm Management. These are included in the outline below for the sake of presenting the work of the office in its entirety.

The work of the Office of Farm Management is divided into five sections, as follows:

(1) Office administration and records.
(2) Farm economics.
(3) Special farm-management studies.
(4) Farm-management field studies and demonstrations.
(5) Utilization of cacti and dry-land plants.

The work of each of these sections is discussed briefly below, but with sufficient fullness to enable the reader to gain a clear idea of the nature and purpose of the work and the methods pursued.

## OFFICE ADMINISTRATION AND RECORDS.

This section is responsible for the care of the library and the various files maintained in the office, such as correspondence and field reports of the staff; for the preparation and care of photographic records; for the revision of manuscripts; and for the financial records of the office.

## FARM ECONOMICS.

The subdivision of the work in the Section of Farm Economics is based partly on methods of investigation and partly on subject matter. The various types of investigation in progress are agricultural cost accounting, farm-management surveys, farm equipment, marketing farm products, agricultural credit, agricultural insurance, and history of farm management.

### AGRICULTURAL COST ACCOUNTING.

Several methods, differing more or less in details, are used in cost-accounting work in the Office of Farm Management. One of these is as follows: Detailed records of all labor performed and of all transactions occurring on a considerable number of farms are received in the office and tabulated in such manner as to show the cost and income of each enterprise on the farm, as well as the general farm expenses which can not be charged to any particular enterprise. This renders it possible at the end of the year to determine the profit or loss from each enterprise, as well as of the farm as a whole.

In this work the Office of Farm Management is cooperating with the Ohio Agricultural Experiment Station, the University of Wisconsin, and the University of Missouri, the records from farms in these States being received and tabulated at the institutions mentioned and copies of the tabulations being transmitted to Washington. The records from farms located in other States are received and tabulated in the Office of Farm Management. The original records are made by the men who do the farm work, on blanks furnished by the Office of Farm Management and the cooperating institutions. Monthly summaries of the labor by enterprises are furnished the owners of the farms, and at the end of the year they are also fur-

nished a complete summary of the records for the year, showing the cost and income for each enterprise and for the farm as a whole.

Another method differs from the foregoing in the fact that the farms furnishing the records are located in a selected locality and are visited at frequent intervals by a representative of the office whose business it is to render such service as may be necessary in keeping the records, and especially to see that the records are properly made. These groups of farms are known as cost-accounting circuits. A representative of the office devotes his whole time to the 15 to 20 farms constituting one of these circuits.

In cooperation with the New York State College of Agriculture at Cornell University the office employs a man who devotes his time to helping a number of farmers in the State of New York to develop systems of bookkeeping for their own use. These systems include cost-accounting records the tabulation of which is done by the farmer himself.

The Office of Farm Management also furnishes to several hundred farmers well distributed over the country a special form of diary, in which the farmer keeps such records as he desires and from which he makes such tabulations as he wishes. Suggestions are made to the farmer as to the records it is worth while to keep and the tabulations that would be of most service. Instructions are also given as to the details of record keeping and the making of tabulations. These books are furnished with the understanding that when they are filled (each book holds six months' records) they will be lent to the Office of Farm Management for the purpose of securing therefrom any data that may be useful in connection with the work of the office. Experience with these diaries has shown that they give much valuable data concerning the cost and income from farm enterprises and still more concerning the dates when various farm operations occur. This latter information is of special value in studying the important question of the seasonal distribution of labor on the farm. Perhaps the most important service they render the office is in showing what records farmers can be induced to keep when it is made easy for them to make the records and the use that farmers will make of such records when they are at hand. The results thus far have been very gratifying.

In the types of cost-accounting investigations just described the work has related to the whole farm. The office also conducts cost-accounting investigations relating to a single enterprise. In this work representatives of the office visit a large number of farms on which the enterprise under investigation is conducted and secure from each the data concerning every feature of the conduct of the enterprise. The data thus obtained represent either the farmer's knowledge of the details of the conduct of the enterprise or the best estimates he is able to make concerning them. The relative accu-

racy of information obtained in this way as compared with that obtained from detailed records kept by farmers, as well as with data obtained in ordinary experimental work, will be discussed later in these pages.

The original purpose of the cost-accounting work was to determine the cost of all classes of farm operations and the relative profitableness of the various crop and live-stock enterprises under different conditions, as well as to develop simple systems of accounting adapted to the farmer's own use. The many important lessons the results of these investigations have taught will be dealt with in other publications. Suffice it here to state that the causes of profitableness have been found quite as often in the scheme of organization of the farm as in the excellence of the methods used, if, indeed, not more often. The fact has been strongly emphasized that a proper selection of enterprises that fit well together, thus giving a satisfactory seasonal distribution of labor, and especially a system that gives full utilization of the farmer's ability, that permits the maximum wise use of power and at the same time so distributes the work as to render necessary a minimum amount of equipment, greatly reduces the cost of production per unit of product, and thus increases the profit in farming. Without such a system there is frequently little or no profit, no matter how well the work of the farm may be done. Thus it happens that while these investigations have resulted in valuable knowledge of the kind originally sought, they also furnish a vast array of facts that are of even greater value than a knowledge of the cost of doing things on the farm.

The following is a partial list of the subjects on which the records obtained in the cost-accounting work furnish data of more or less value:

Kind and number of operations required by every enterprise.

The dates when these operations may or must be performed.

The character of crew (men, horses, and machinery) required for each operation.

The amount of work these crews perform in a day, and hence the time required for each operation.

The proportion of days in a given period that are available on the average for field work, or, to state this conversely, the proportion of time lost from rain, holidays, necessary trips to town, unavoidable delays, and the like.

Cost of production and income from the various farm crops and types of live stock under a wide range of conditions.

The general farm expenses, or the "overhead charges," on the productive enterprises of the farm.

The returns per hour of labor spent on different enterprises.

The amount of use, and hence the cost per acre and per unit of product, of each item of equipment.

The rate of depreciation of farm equipment of all kinds. This is determined in two ways: (1) From the successive annual inventories and (2) from the

length of time an implement lasts and the amount of work it does. This second method is, of course, possible only on farms for which records are secured for a number of years.

Length of the working day.

Time required for "chores" on farms of different sizes and types.

The relation of all phases of farm practice to crop yields.

The practicability of various crop rotations.

The conditions to which various farm enterprises are suited.

The relative profitableness of different enterprises.

Crops which compete and those which do not compete for labor at the same time of the year.

Relation of the size of farm to profit.

Relation of the type of farm organization to profit.

The cost of marketing farm products.

The rate of income on capital invested in farming.

The labor income of the farmer.

Distribution of capital between the various factors of production, such as land, buildings, fences, work stock, productive stock, implements and machinery, etc.

Cost of housing and feeding farm animals.

Cost of horse labor.

Cost of man labor.

Types of records adapted for use by the farmer.

It is clear, therefore, that these investigations cover practically the whole field of farm management. But unfortunately the securing of complete records of all the work done on a large number of farms is both tedious and costly. It would require many years and the expenditure of vast sums of money to secure all the data needed on farm-management subjects in this manner. Some of the kinds of data in the above list can be obtained in no other way, but many of them can be secured in greater quantity by cheaper methods, as will appear in the accounts of other types of investigation described in what follows.

#### FARM-MANAGEMENT SURVEYS.

Another important line of investigation conducted by the Section of Farm Economics is the farm-management surveys. In this work localities are selected that are believed to be representative of important agricultural regions and studies are made on every one of 500 or 600 contiguous farms, no farms being omitted from which it is possible to obtain the necessary data. These surveys are intended to reveal the actual status of the agriculture of the regions in which they are made.

Sufficient data are obtained from each farm to enable the investigator to determine the amount of capital invested, the value of all the major items of equipment, the amount and character of the farm expenses and receipts, the increase or decrease in the farm inventory for the past year, and all other facts necessary to determine the labor income of the farmer after deducting interest on the

investment and wages for the unpaid labor done by members of the farmer's family other than the farmer himself.

The data obtained also permit the study of such questions as the relation of profits in farming to the education of the farmer, the relation of the age of the farmer to the percentage of tenant farming, the effect of distance from markets on the value of farm land, and numerous other questions of importance to agriculture in general.

Some very important results have been obtained in studies of this kind and some time-honored opinions on matters of importance have been shown to be erroneous. Detailed results of these surveys are published from time to time in the series of bulletins issued by the Bureau of Plant Industry, and it is therefore unnecessary to discuss these results at length here.

A word as to the accuracy of the results obtained in these surveys. The data obtained from the farmers represent their knowledge, and in cases where they do not have definite knowledge, their estimates as to the details of the farm business during the year just past. It sometimes happens that it is possible to test the accuracy of the results thus obtained. This was the case in one detail of a recent survey made by this office in one of the New England States.

Among the several hundred farms included in the survey were 135 that sold milk to creameries. Each of these farmers was asked to give as accurate an estimate as possible of the amount of money he had received for this milk. After the survey was partially finished it occurred to the investigator that it would be possible to secure a check on the accuracy of these estimates by obtaining the actual figures from the creameries themselves. It was decided also to test in a similar manner the farmers' estimates of the quantity of milk each had sold to the creamery. The estimates as to quantity of milk sold were then obtained from the 79 farms visited after the decision had been reached to make this test. These farmers did not as a rule weigh their own milk and were not accustomed to dealing with weights as they were with sums of money; it was to be expected, therefore, that the estimates of quantity of milk sold would be less accurate than those of money received, and this was the case, as will be shown below. After obtaining the estimates from the farmers, the actual figures, both for weights of milk sold and for money received, were secured from the creameries that had purchased the milk.

| | |
|---|---|
| Estimated pounds of milk sold (79 farms) | 3,518,816 |
| Actual pounds of milk sold (79 farms) | 3,487,320 |
| Difference | 31,496 |
| Estimated value of milk sold (135 farms) | $106,163.00 |
| Actual value of milk sold (135 farms) | 106,155.50 |
| Difference | 7.50 |

It is seen that the error
than 1 per cent of the wh
mates of pounds of milk s
40 per cent above to 36 ]
total these errors tended
sum of the estimates was
in terms of which the fa
the total is less than one-
will serve to show somethi
the results of the farm-
another source of error i
data obtained apply only
the results therefore may
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repeat the work for severa
be done in all cases where
tions are abnormal during
in the locality.

The relative accuracy o
experience and from dat
further notice here, in view
represented by the study
hitherto and its value is
agricultural problems. It
inaccuracies of plat experi
causes, such as the variati
tions in seasons which affe
the accuracy of final resul
of a number of separate ol
are to be considered, i. e.,
each average and the accu
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It is a well-established
being equal, the reliabilit
root of the number of obs
this standpoint the metho
practice has a very distinct
on account of the vastly la
with a given expenditure
course, that the problem is
farm experience, whether
of the fact or not.

The relation of the accu
of the original observation
experimental work, and co

by attempting to secure great accuracy in one of the controlling factors in the case when the results are rendered inaccurate by inaccuracy in others. A chain is not made stronger by strengthening the link which is already strongest. If great variation in the yield of a crop, for instance, is due to irregularities of the soil and to variations in seasons which affect different plats differently, then no great increase in the degree of accuracy in the final result is obtained by using extreme care in measuring areas of plats and yield per acre. This point is illustrated in figure 1.

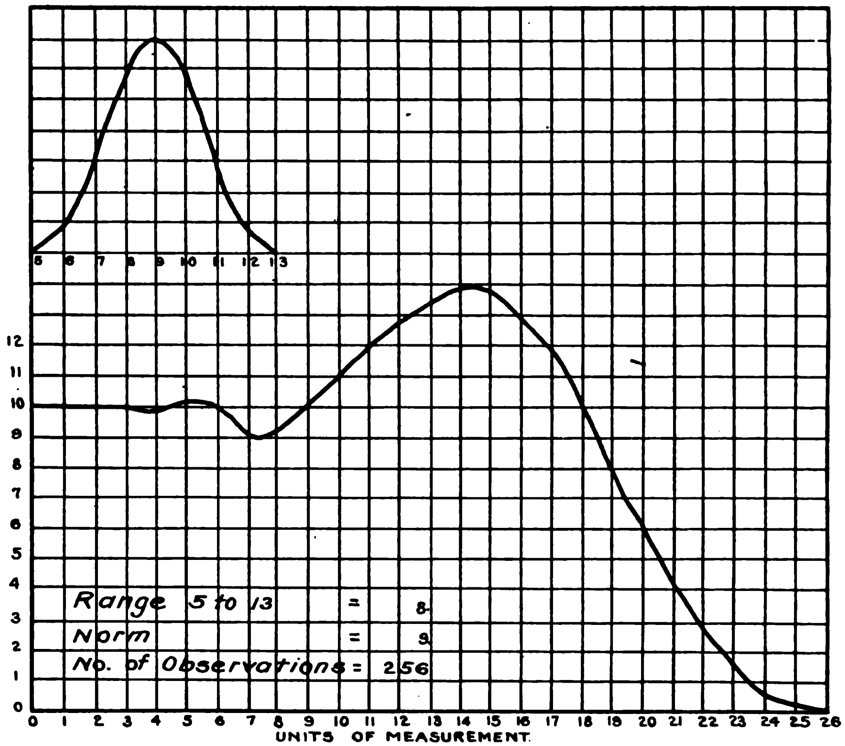


FIG. 1.—Diagram showing the relation of the accuracy of an average to the accuracy of the numbers averaged.

The upper curve in this diagram is a frequency curve for a series of 256 observations of a variable quantity whose range of variation is from 5 to 13 on the scale adopted in the diagram. This degree of variation is comparable to that of the yield of a crop in plat experiments covering a series of years or a series of plats side by side the same year. The true average of the 256 observations in this case is 9. If instead of the true values of the observations, made originally, say, to the second decimal place, we take in each case the nearest unit, the average is still 9, as shown in the lower curve of the diagram. In this lower curve the figures at the bottom (abscissas)

represent the units of measurement used in making the observations to be averaged, and the ordinates of the lower curve show the corresponding averages. It is seen that the inaccuracies of the averages are too small to represent in the diagram until the unit in which the measures are made reaches the magnitude of three divisions of the scale, which is three-eighths of the whole range of variation of the variable. In other words, we make no essential gain in accuracy of the final average by making the original observations more accurately than to use a unit equal to three-eighths of the range of variation.

It should be stated that this conclusion does not apply to all kinds of averages, but it does apply to those cases in which the observations form a frequency curve of approximately the form shown in the diagram (upper curve). This means that in determining the average yield of a crop that varies from year to year by as much as 24 bushels per acre, when the number of experiments is large, we make no appreciable gain in accuracy by using a unit of measurement smaller than 9 bushels. Thus, if any yield between 4½ and 13½ is recorded as 9, yields from 13½ to 22½ as 18, from 22½ to 31½ as 27, and so on, the final average, if the number of yields in the average is considerable, will be approximately as accurate as if the yields had been determined to the hundredth part of a pound per acre. In other words, when the number of observations is large, a series of guesses by those who can make reasonably good guesses gives a result about as reliable as the most accurate measurements when the quantity to be measured or considered is highly variable. On account of the importance of this matter and the fact that these principles are not generally understood except by students of the theory of probabilities, further illustration of them is given below.

In the American Naturalist for April, 1909, Dr. R. Pearl, of the Maine Agricultural Experiment Station, shows that in the measurement of the length of 450 hen's eggs to the nearest millimeter only the average of these measurements is correct to the nearest hundredth of a millimeter; i. e., the average was more accurate than the measurements on which it was based.

Again, the mean annual rainfall at Philadelphia for a period of 66 years, from 1826 to 1891, inclusive, was 43.2 inches, the measurements being made to the nearest tenth of an inch. At the end of the first 10 years of these observations the annual mean was 40.4 inches. There is no doubt that the mean for 66 years is more nearly the true value of the mean than that for 10 years. Taking the 66-year mean as the true value, the 10-year mean is in error to the extent of 2.8 inches. If, now, instead of the true value of the rainfall each year we take the nearest 10 inches, so that, for instance, any rainfall between 25 and 35 inches is recorded as 30 inches, the

average thus obtained for the 66 years is 42.9 inches, an error of less than 1 per cent of the true average, while the 10-year average from accurate measurements is in error over 6 per cent. Not only that, but the 66-year average when precipitation is recorded to the nearest multiple of 10 inches agrees more closely with the 66-year average made from records reading to the tenth of an inch than does the average of any of the 10-year periods during the first 60 years of this time, even when the data on which the 10-year averages are computed is highly accurate. This shows that in securing the average value of a variable quantity the number of observations is more important than precision of measurement.

Enough has been said to show that data collected from farm experience, if sufficiently abundant—and they can easily be made so—give results even more dependable than the results of the ordinary plat experimental work. Data so obtained compare favorably with the best plat experiments when the subject under investigation is adapted to this method of investigation.

Farm-practice results secured by this method relate to real farm problems, which can not always be said of experiments planned in the experimenter's office.

### FARM EQUIPMENT.

While the cost-accounting work was primarily intended to determine the cost and profit of farm operations, we have seen that incidentally it furnishes much valuable information relating to practically every phase of farm management. The farm-management surveys, while not covering so wide a range of subjects, still cover a good part of the field. These two divisions of the work represent different methods of investigation rather than different fields of investigation. On the other hand, the investigations relating to farm equipment represent one of the subdivisions of the science of farm management as outlined in Part I of this bulletin. The methods used in the investigation of equipment problems are closely similar to those used in the farm-management surveys, though they are more detailed than the latter, much more time being given to the equipment of a given farm or enterprise. The data regarding equipment are in the main obtained by personal visits to the farms studied, careful inventories of the various items of equipment being made.

The factors which determine equipment are, in many instances, numerous, variable, and complex, for which reason the necessary or justifiable equipment for given conditions can, in many cases, be ascertained only through experience. At the same time such wide variation exists in practice that the true resultant of the forces which control equipment can only be found by considering a large number

of cases, for it is necessary to have large numbers of observations in order to secure reliable averages. Hence, methods that are more rapid and less expensive than those used in the cost-accounting work are better adapted to the solution of the main problems of farm equipment. The method already outlined (see p. 29) for ascertaining the proper or permissible cost of the farm dwelling illustrates well the general method of attacking the more complex problems relating to farm equipment. We can not solve such a problem simply by determining the number of individuals to be housed and the number of cubic feet of inclosed space each requires, for people differ in taste both as to the amount of space needed for each individual and as to the appearance of the inclosed space, viewed either interiorly or exteriorly. We can, however, ascertain how much it is safe financially for the farmer to expend in inclosing this space. But the forces that determine this limit of safety are subtle ones that can not be measured directly; we can only measure their general resultant by taking the averages of large numbers of cases.

Similarly complex and subtle forces determine many other features of farm equipment, though in many cases it is possible to determine equipment needs more directly from the definite relations existing between character of equipment and the nature of the thing to be accomplished. Thus, when a system of cropping on a farm is once determined, it is possible, in many cases at least, to state at once certain items of equipment that will be necessary, or at least highly desirable, in carrying out this system. But if a farm has 20 dairy cows, 10 head of young stock, 5 work horses, and 40 ewes, it is not so clear just what buildings this complement of stock necessitates or what these buildings should cost. It is possible, by taking account of the stock to be sheltered and the amount of feed for them that must be stored, to determine quite accurately the amount and character of the inclosed space needed; but how much money the farmer would be justified in putting into these structures must be determined in another way. Many farmers would settle such a question by building the cheapest structures that would answer the purpose, even inadequately. Others would desire more adequate, and even ornate, structures. An actual census of the farm buildings on farms having the above complement of stock would undoubtedly show a variation of 200 or 300 per cent or more in the cost of the buildings in use. In building a cow barn, for instance, it is possible to secure shelter for the cows and their feed at a cost per head of less than $2, though perhaps not adequate shelter. Yet cow barns exist in this country that cost over $2,000 per head for the animals sheltered. What sum is the farmer justified in putting into such a structure? This is a question that can be answered only by a careful study on a large number of successful dairy farms. The fact that a farm is successful

is evidence that in such matters it has not far transgressed the limits of prudence on the one hand or of adequacy on the other. The study of actual practice on a large number of successful farms is thus the best means of arriving at the solution of many of the problems relating to farm equipment.

A few farmers are able to determine quite accurately their needs in the way of equipment, but the vast majority of them make more or less serious mistakes. Especially is this likely to occur when the farmer changes his type of farming and takes up one or more enterprises with the equipment of which he is not familiar. A great deal of money is wasted in equipment that is not needed or is not suited to the purpose it is intended to serve. On the other hand, many farmers obtain poor results for lack of suitable equipment, and this is not always because they can not afford to buy the needed equipment, but because they do not know what they need. Because of these facts the Office of Farm Management has undertaken to ascertain what is adequate and satisfactory equipment, so far as this is possible, for the conduct of farms of all sizes and types in all sections of the country. The mere fact that the actual equipment in use for accomplishing the same thing varies widely on different farms does not present an insurmountable obstacle in the investigation of this question, though it does make the problem difficult. It is, however, rendered much more complicated by the fact that changes in the type of farming are continually going on in nearly all sections of the country. But the fact that these changes are going on makes the work all the more urgent.

The following is a brief outline of the more important subjects under investigation relating to farm equipment:

Distribution of capital between the various factors of production: The relative amount of capital invested in land, buildings, work animals and other stock, implements and machinery, supplies, and ready cash for current expenses on farms of different sizes and types in different climatic regions.

The farm dwelling: Its cost, peculiarities of farm dwelling as contrasted with city dwellings, interior arrangement, design, and construction.

Other farm buildings: Amount and character of inclosed space needed under given conditions; space units per animal; the arrangement of the inclosed space in relation to convenience and economy; the location of buildings with reference to each other and to the farm as a whole; farm practice in design and construction of farm buildings and the principles involved in the same; the cost of buildings under all conditions; the cost of keeping buildings of different types in repair; and the rate of depreciation of buildings.

Farm fences: Conditions requiring or justifying fences; relation of the layout of the farm to economy in fencing; types of fences and their uses; the cost of fences of different types; the cost of materials for all kinds of fences; the amount of labor required in constructing fences; the cost of keeping fences in repair; and the rate of depreciation of farm fences.

Water supply and sewage disposal on the farm: Types of equipment and cost and practicability of the same.

Systems of heating and lighting farm buildings and the cost of installing and operating the same.

Equipment of farms of a particular type.

Relation of the size of the farm to the character, especially the size, of the equipment.

Equipment for particular enterprises.

General farm equipment: Equipment that can not be charged directly to any one of the productive enterprises of the farm. Equipment of this kind accounts for part of the general farm, or "overhead," expenses, which must be apportioned between the productive enterprises in determining the profit of these enterprises.

Minor items of equipment: This includes those small items that are never, or at least seldom, enumerated separately in the farm inventory, but are lumped together under the general title "small tools, etc." One important study of this kind has already been published. (See Circular 44, Bureau of Plant Industry, entitled "Minor Articles of Farm Equipment.")

Equipment for particular operations: This includes a study of the wide variation in farm practice in performing the same work and of the causes underlying this variation; the cost of a given operation when performed with different equipment; and a complete study of crew work of all kinds, including the number of men and horses in the crew, and the number, kinds, and sizes of implements or machines used by the crew, as well as the part each member of the crew plays in the operation.

Duty of machinery: This is a study of the amount of work a machine or implement does, or should do, in a given time, such as an hour, a day, or a working season.

Standards of farm labor: A study of the amount of labor that may fairly be expected of a farm laborer under all conditions and in all kinds of farm work. Data of this kind are of enormous value in the management of hired labor, as well as in planning in advance a season's work or in making out a working plan for a farm.

The proportion of time available at different seasons of the year for work of different kinds, especially for field work.

The amount of labor and the number of work animals needed on a given farm at different seasons of the year.

Equipment charges: The rate of depreciation of farm equipment of all kinds; the cost of repairs; the cost of housing implements and machinery; the rate of interest on money invested in equipment of different kinds; and the amount of annual use of equipment and its bearing on the equipment cost of farm operations.

The conditions, especially the amount of use, that justify the purchase of a given item of equipment; conditions which make hiring more desirable than the purchase of equipment.

Advantages and disadvantages of joint ownership of the more expensive machines and implements.

Use of mechanical power instead of horse power on the farm. (See Bulletin 170, Bureau of Plant Industry, entitled "Traction Plowing.") Attention is given to types and sizes of tractors in use; conditions to which the various types are best adapted; conditions which justify the purchase of a tractor; the original cost, the cost of repairs, and the rate of depreciation of farm tractors; the cost of operation and the crews and supplies required; the amount of work done per day and per season; and the cost per unit of work done.

The Office of Farm Management receives numerous inquiries as to the relative merits of different makes of implements designed for the same work. These are problems in farm engineering and are not strictly farm-management problems. To answer such inquiries would involve long and painstaking research, requiring extensive laboratory equipment, necessitating exhaustive inquiry into methods of mechanical design, construction and efficiency, the strength and adaptability of materials, etc., all of which are lines of work requiring a different education and training and a different point of view from that of farm management. It would also involve complications with the patent laws if undertaken under Government auspices. This fact and the further fact that such investigations might involve conflicts with private inventors and manufacturers who are spending much time and money in such investigations have hitherto operated to prevent the appropriation of public funds for the study of such problems. But the opposition of manufacturers to investigations of this character has largely disappeared, and would entirely disappear if such modifications of the patent laws could be devised as would both protect the inventor and at the same time give every manufacturer the privilege, under proper supervision and control in the interest of the inventor, of using any patented device that would improve the articles manufactured by each. Even at the present time manufacturers would quite generally welcome public engineering laboratories and test stations that would furnish data as to the mechanical types that would be best adapted to farm needs in the various agricultural sections of the country. Such investigations would save both the farmer and the manufacturer millions of dollars now wasted in poorly designed and constructed machinery.

## HISTORY OF FARM MANAGEMENT.

Ancient and medieval literature regarding farm management, while by no means extensive, is yet sufficient to enable the careful student to gain a fair idea of economic conditions in agriculture at most stages in the history of European nations. This is especially true of Italian agriculture during the days of the Cæsars and of English agriculture practically from the time of the Roman occupation, near the beginning of the Christian era. In the period during which the Romans produced their most enduring literature it was fashionable for scholarly men to own country estates, and no small amount of literature is extant relating to the management of these estates. It has always been fashionable for the English nobility to own land and to farm it. Even in the early centuries of the Christian era it was the custom on country estates in England to keep fairly complete records of farming operations. A careful

study of this old literature is being made in order to summarize for publication such of it as will interest farmers.

The three subjects following belong to rural economics rather than to farm management, but are investigated in this office on account of their intimate relation to the subject of farm management, as well as for administrative reasons.

### MARKETING FARM PRODUCTS.

A study is made of the methods used in different parts of the country in preparing farm products for market, especially those that go to the ultimate consumer in the form in which they leave the farm, with special reference to the effect these methods have on the prices received; methods used in transporting farm products, especially perishable products, to distant markets, and the relation of these methods to market values; methods of organizing and conducting cooperative marketing associations; the effect these associations have on the net returns received by the farmer; the distribution of enterprises with relation to the market centers; and finally the difference between prices received by the farmer and those paid by the consumer and the reasons for this difference.

### AGRICULTURAL CREDIT.

An investigation is made of the sources of available credit for the farmer, the conditions under which the farmer may obtain credit for financing his operations, and the rates of interest on farm loans. It also includes a study of the details of organization and operation of agricultural loan associations, both in America and in Europe, with special reference to those features which adapt these organizations to American conditions.

### AGRICULTURAL INSURANCE.

This is a study of forms of insurance most patronized by farmers, and especially of farmers' mutual insurance societies, their organization and conduct, and the rates of insurance paid. Attention is given to life, fire, crop, live-stock, and all other forms of insurance, but especially to those forms conducted by farmers' mutual organizations.

## SPECIAL FARM-MANAGEMENT STUDIES.

In conducting farm-management field studies the country may be divided into geographic sections and men assigned to each of th sections for the purpose of studying the farm-management pr that present themselves, as is done in the Office of Farm Ma in the case of the broader and more fundamental probl may be assigned to a particular problem without restr

territory covered, being guided in this matter by the geography of the problem itself. In this office this latter method is pursued in the case of problems which, however important they may be, are not of sufficient magnitude to justify assigning more than one or two men to their investigation or which are only distantly related to the major problems of farm management. These problems are here brought together under the above heading. Some of them are inherited from the old Office of Grass and Forage-Plant Investigations, out of which the Office of Farm Management developed, and were left in this office when the new Office of Forage-Crop Investigations was organized, either because of the personal interest of certain members of the staff in the problems in question, because they involved certain phases of farm management or because there was no other office in the Bureau of Plant Industry that was directly interested in them. Some of them, however, relate strictly to fundamental problems in farm management. These special problems follow.

### TENANT FARMING.

The lack of further opportunity for taking up desirable public lands in our Western States and the consequent general rise in the price of farm lands practically all over the country has resulted in an increase in tenant farming, especially in those sections where land values have risen to the point at which it is exceedingly difficult for the purchaser of a farm to meet both living expenses and interest on his indebtedness and also make payments on the principal. It can hardly be doubted that tenant farming will further increase in this country and that ultimately the land will largely be owned by the wealthier classes and be farmed by tenants with moderate capital.

It is to be hoped that the work which the National Government and the States are now doing for the benefit of the farming classes will ultimately enable a larger percentage of farmers to own the land they farm; but the problems relating to tenant farming are not only important at the present time, but are likely to become more so. Two phases of the subject are receiving special attention in this office at the present time. One of these relates to the amount of working capital required to conduct a farm properly, especially with a view to maintaining the fertility of the soil, and the possibility of inducing the landlord to furnish this capital where the tenant is unable to do so. The other relates to the details of the contract between landlord and tenant. Both the cost-accounting work and the farm-management surveys, as well as the farm-equipment studies, furnish much valuable information on the first of these two problems, but it is also receiving direct study as a separate problem by a careful study, especially of those tenant farms that are being conducted in a satisfactory manner.

Sufficient discussion has already been given the problem of the contract between landlord and tenant (pp. 31–32) to give the reader an idea of the phases of the subject that are under investigation. Investigations thus far conducted indicate that the central problem in the contract is the share of the farm income that is to go as reward for labor and the share that shall constitute the income on capital invested. On certain large estates that have for many years been let to tenants and on which the securing of satisfactory tenants is a major problem this problem of labor's share of the farm income has been quite definitely solved, that is, it has been worked out what proportion of the income must go to labor in order to secure and hold desirable tenants. There are many such estates in this country, one of them consisting of 200,000 acres of as good land as the country affords. The results of these investigations will be given in separate publications. (See Farmers' Bulletin 437, entitled "A System of Tenant Farming and Its Results.")

### RELATION OF GEOGRAPHIC FACTORS TO THE DISTRIBUTION OF FARM ENTERPRISES.

Types of farming and farm enterprises generally find their proper place in the agriculture of any country. But the process, unaided by science, is slow and exceedingly expensive. Millions of dollars have been wasted by the farmers of this country in finding out what crops, types of live stock, and farm-factory processes are adapted to each of the various agricultural sections of the country. Very little serious attempt has been made to ascertain what are the real limiting factors in the distribution of these enterprises. The Office of Farm Management is undertaking a general study of the relations existing between the distribution of enterprises and such geographic factors as the amount of rainfall, the seasonal distribution of rainfall, the length of the growing season, the dates of the last frost in the spring and the first frost in the fall, and the topography, elevation, latitude, geological formation, and character of the soil.

### CLEARING AND UTILIZATION OF LOGGED-OFF LAND.

There are yet many millions of acres of land to be cleared for farming. This is mostly land from which all the merchantable timber has been cut; hence the designation "logged-off land." Much of this land has lain unused for many years because of the expense of removing the stumps from the ground. Now that free land ready for the plow is practically a thing of the past, these logged-off lands assume an importance they did not possess a few years ago.

The study of the problems of clearing and utilizing logged-off land, though not strictly a subject for farm-management investiga-

tions, has been carried on by the Office of Farm Management for reasons already suggested, and this office is investigating the methods in use in the various sections of the country where these lands are being put into cultivation, as well as studying problems connected with the improvement of these methods. (See Bulletin 239, Bureau of Plant Industry, entitled "Cost and Methods of Clearing Land in Western Washington.")

### RELATION OF FARM PRACTICE TO CROP YIELDS.

Probably more effort has been given to the attempt to learn how to increase crop yields than to any other single problem in agriculture. While much has been learned, we are yet far from having a satisfactory understanding of this most important subject. All over this country, at least in the older settled sections, there are farms on which definite systems of farming have been followed for a sufficient length of time to permit the system to have produced whatever effect it will on the fertility of the soil. The Office of Farm Management is engaged in gathering up careful records of these systems, especially those that give satisfactory crop yields, with a view to studying, by means of comparison of the different systems and the resulting yields, especially those under similar climatic and soil conditions, the effect different elements in the systems have on the yield of crops.

### FARM MANAGEMENT IN SUGAR-BEET CULTURE.

The different viewpoints of farm management and agronomy with reference to a crop were fully discussed on page 14. In the case of sugar beets the agronomist is concerned with the methods to be used in order to produce the greatest tonnage of available sugar per acre. The investigator in farm management is concerned with the equipment required for the production of beets, with the labor necessary and the distribution of this labor during the season, and also with the relative profitableness of this crop as compared with others to which the farmer might devote his land; in short, with the economic conditions which render sugar beets a desirable farm enterprise. Studies of this character are in progress, in cooperation with the Office of Sugar-Plant Investigations.

Exactly similar studies are being made of all the leading farm crops of the country, but for the most part these studies are made incidentally in connection with the farm-management field studies to be described later in this bulletin.

### WEEDS AND TILLAGE IN RELATION TO FARM PRACTICE.

Farm practice in weed control and in the matter of tillage is more closely related to the work of the Office of Farm Management than to that of any other office in the Bureau of Plant Industry, for which

reason this work is conducted in this office. It is a line of work which developed out of the attempt to find a method of eradicating Johnson grass, which attempt was entirely successful (see Farmer's Bulletin 279, entitled "A Method of Eradicating Johnson Grass") and thus represents an inheritance from the old Office of Grass and Forage-Plant Investigations. While both lines of work (weed control and tillage) are studied mainly from the standpoint of farm practice, some experimental work is conducted on both of them.

The distinctive method of weed investigation developed in this office consists of a detailed study of each weed for the purpose of ascertaining its complete life history, especially the methods of propagation possible to it. The season of the year at which seeds, rootstocks, bulbs, and other parts capable of originating new plants are formed, as well as the stage of growth the mother plant must reach in order to be able to form these propagating parts, and the length of life of any part of the plant capable of originating new individuals are accurately determined. In the case of most perennial weeds thus far investigated this knowledge has pointed to certain easy methods of eradication. Thus, in the case of Johnson grass, the weedy character of which arises from the freedom with which it produces rootstocks, the rootstocks do not begin to form until about the time the plant has reached the blossoming stage. If the plant is cut back, as in mowing hay, before the rootstocks are formed, the energies of the plant are then directed toward throwing up new aerial growth instead of the development of rootstocks. If the plants are kept cut back during the whole season rootstocks do not develop until late in the season, and then only feebly. It is only these newly formed rootstocks and the crowns of the old plants (and, of course, the seeds) that will give rise to new growth the next year. A single very shallow plowing late in the season, after the plants have been cut back so as not to allow them to produce blooms during the summer and before the rootstocks have made more than the merest start to form, thus completely destroys the plant and leaves no means of propagation for the following season. By taking advantage of these facts clean crops of cotton have been grown on land from which Johnson-grass hay had been cut the previous season. Similar studies have been made of wild onion and of quack grass, and easy methods for the eradication of both of these pests have resulted (see Farmer's Bulletin 464, entitled "The Eradication of Quack-Grass," and Circular (Document 416), Bureau of Plant Industry, entitled "The Wild Onion").

Particular attention is now being given to the relation of weeds to the various crop rotations practiced in different sections of the country.

Investigations of farm practice in the methods of tillage in all parts of the country are in progress, the object being to ascertain what are the fundamental causes of present practices, as well as the bearing of economic conditions on methods in use in different sections. Is the 15-inch sweep used for cultivating cotton in so many parts of the South due to the meager amount of power necessary on a one-man cotton farm or is this implement actually the best type of implement to accomplish the purpose for which it is used? Some recent results of tillage experiments conducted in this office seem to indicate that implements of the type (but not necessarily of the size) of the sweep are, in fact, the logical implements to use for tillage of crops like cotton and corn. These investigations point very strongly to the conclusion that the object of cultivation on soils that are well filled with growing plant roots is not to create a mulch but to kill weeds. If this is true, the sweep, or scrape, may be the best implement now available for the tillage of growing crops.

The methods used and the results obtained in these tillage experiments are given in detail in another publication (see Bulletin 257, Bureau of Plant Industry, entitled "The Weed Factor in the Cultivation of Corn").

### FARM-MANAGEMENT FEATURES OF HAYMAKING AND THE UTILIZATION OF THE HAY CROP.

The farm-management features of haymaking relate to the amount and kind of labor required and the season of the year when this work must be done. They also include the cost of producing hay and the best manner of utilizing the crop as a source of revenue on the farm. One other feature of haymaking that is receiving attention is methods and cost of curing hay by artificial heat. The labor distribution on the hay crop is, of course, studied from the standpoint of farm practice. The work on artificial curing is experimental. This work is slow and expensive, and it will be some years before positive results can be announced. (See Farmers' Bulletin 508, entitled "Market Hay.")

### PASTURES AND CROPPING SYSTEMS FOR LIVE STOCK.

The study of problems relating to the maintenance of pastures and the place of pastures in the economy of the farm was begun in this office before it was converted into the Office of Farm Management, and certain phases of this study are still continued in cooperation with the new Office of Forage-Crop Investigations. A study of the practice of those stock farms which maintain pastures in productive condition is being made. Problems relating to the renovation of worn-out pastures are under investigation in cooperation with the office last mentioned. Special attention is being paid to the cropping systems used on successful stock farms in all sections of the country.

## FARM-MANAGEMENT FIELD STUDIES AND DEMONSTRATIONS.

### RELATION TO THE FARMERS' COOPERATIVE DEMONSTRATION WORK.

In the cotton-producing States, including Virginia, North Carolina, South Carolina, Georgia, Florida, Tennessee, Alabama, Mississippi, Arkansas, Louisiana, Oklahoma, and Texas, the work of the Section of Farm-Management Field Studies and Demonstrations of the Office of Farm Management is confined to the investigation by the study of farm practice of problems relating to farm organization and farm operation, all the demonstration work in these States being conducted by the Farmers' Cooperative Demonstration Work, which constitutes a separate office in the Bureau of Plant Industry. Although this investigational work is conducted in close cooperation with the Farmers' Cooperative Demonstration Work, the two are administered independently. In other States this section of the Office of Farm Management conducts both investigations and demonstration work, and no effort is made to keep the two types of work separate, the same staff conducting both.

### ORGANIZATION.

In the administration of the work of the Section of Farm-Management Field Studies and Demonstrations of the Office of Farm Management the country is grouped into three divisions, as follows: The North Atlantic and North-Central States, the South Atlantic and South-Central States, and the Western States. The second of these divisions includes the cotton States, in which, as above stated, the Office of Farm Management does no demonstration work, and, in addition, includes the States of Delaware, Maryland, West Virginia, and Kentucky, in which the office conducts both investigations and demonstrations. It is probable that as the demonstration work of the office grows the first of the divisions specified will be separated into two. A division leader has charge of the work in each of the foregoing groups of States. Another assistant to the section leader has charge of the boys' and girls' agricultural club work in all the States except those in which the Farmers' Cooperative Demonstration Work is organized. In these States the latter office has charge of this work.

Each of the geographic divisions mentioned is subdivided into groups of a few States each, and the division leader has an assistant in each of these groups of States. These assistants are known as district leaders. They devote their time mainly to the investigation of farm practice, but assist in the supervision of demonstration work. In the cotton States their whole time is devoted to investigational work. The investigational work conducted personally by the leader of this section of the office, by the division leaders, and by the district leaders is not conducted in direct cooperation with State agencies.

But all demonstration work conducted by the office and such investigations as are conducted by those in local charge of the demonstration work are conducted in cooperation with State agencies in the manner outlined below wherever it is possible to arrange for such cooperation.

The recent development of the demonstration work conducted by this section of the Office of Farm Management has made necessary an extension of the foregoing plan of organization in order to provide adequate supervision of the demonstration work and to facilitate cooperation in this work with State agencies. The general plan for this extension of the organization of this section of the office is outlined below. This plan is modified as occasion requires to suit the exigencies of the institutions in cooperation with which the work is done.

A State leader who has general charge of farm-management field studies and demonstrations in the State is employed jointly by the United States Department of Agriculture and the cooperating institution, the salary and expenses of this man being paid jointly by the two parties to the cooperation. It sometimes happens that when the work is first instituted in a State only one of the cooperating institutions is provided with the necessary funds. In such cases the institution having the funds bears the expense until such time as the other can secure funds for this purpose. At the inception of this work in a State it also sometimes happens that the number of men employed as county demonstrators is small and the State man has been permitted to work entirely for the State institution for a portion of the year, usually devoting his time to the teaching of farm-management subjects, the entire salary of the man during such employment being paid by the State institution. But this arrangement is in all cases looked upon as temporary, for with the full development of the investigational and demonstration work the entire time of the State man will be required for its supervision and conduct.

The plan of organization of the work under the direction of the State leader is as follows: Local agents are stationed in the various counties of the State and are made responsible for the conduct of demonstration work and the investigation of local problems in the county. The salaries and expenses of these local men are borne jointly by the Department of Agriculture, the State, and the county, assisted by organizations or individuals who may be interested in the work. In cases where the State or county can not provide funds for this purpose the expenses are borne jointly by the department and private organizations or individuals. In the past the local funds have been provided partly by the county and partly by chambers of commerce, farmers' organizations, banks, railroads, and individuals who are interested in the development and improvement

of the local agriculture. In several States the legislatures have empowered the county authorities to appropriate funds for this work.

The counties in which local agents are employed are grouped together into districts of about 10 counties each, with a supervisor at the head of each. The county men report to and work under the direction of these supervisors, who in turn are under the direction of and report to the State leader. Where State or local funds are available for the purpose, the salaries and expenses of the supervisors are paid jointly from these State or local funds and funds from the Department of Agriculture; otherwise the department provides the funds.

Copies of all results obtained in the investigation of farm practice, as well as all records of demonstration work done and results obtained by the State leader and the staff working under his direction, are furnished both to the cooperating State institution and to the Department of Agriculture. The character of both the investigational work and the demonstration work to be done in any case is agreed upon by the parties to the coöperation, and the State man in charge works under the joint direction of a designated representative of the cooperating State institution and the division leader in the Office of Farm Management. The cooperating institution furnishes office facilities to the State man, and similar facilities are furnished to the county agents by the counties or by local organizations or individuals. The local agents devote most of their time to demonstration work and comparatively little time to investigational work. The time of the supervisors is more largely devoted to field studies. State men and the division and district leaders devote their time to the investigation of farm-management problems by the study of actual conditions existing on the farms in their respective territories and to the supervision of the demonstration work.

## OBJECTS.

The objects to be accomplished by the work of the Section of Farm-Management Field Studies and Demonstrations of the Office of Farm Management may be briefly stated as follows:

(1) To carry to the farmer the results of scientific research in his behalf, as well as the results of the experience of other farmers, and to aid the farmer in applying these results in his work.

(2) To reorganize and redirect the agriculture of the various sections of the country in such a way as to secure on each farm not only enterprises that are profitable in themselves, each being so conducted as to bring maximum net returns, but also to secure a system of enterprises that will permit the largest economical use of power, capital, and labor possible under the conditions, and which will give as nearly as possible an even distribution of labor and a full utilization of equipment throughout the year.

In this section of the office the results of the investigations of other sections of the office, as well as of other offices of the Bureau of Plant Industry, find their final application on the farm through the work of local agents engaged in extension work.

### PROBLEMS AND METHODS.

The investigations of the Office of Farm Management have shown that the principal factors of profitableness in farming are as follows:

(1) Character of the enterprises constituting the basis of the farm business.

(2) Amount of power used per individual employed.

(3) Amount of capital employed.

(4) Distribution of capital between the factors of production, such as land and buildings, work stock and other animals, implements and machinery, etc.

(5) Amount of labor (profitably) employed.

(6) Seasonal distribution of labor and maximum utilization of minimum equipment.

(7) Systems of management of the individual enterprises.

(8) Methods of marketing.

The selection of enterprises that are to constitute the basis of the farm business has been considered quite fully in the first part of this bulletin. (See pp. 9–14.) A summary of the factors which determine what enterprises are adapted to given conditions is given on page 13. A great deal depends upon the wisdom with which the selection of enterprises is made. The study of this question is a very important part of the work of those connected with this section of the office. This is especially true of the work of the county agents; the supervisors who have charge of groups of counties; and especially of the district leaders, who have charge of a group of States. Very frequently it will occur that some crop or some type of live-stock farming is well adapted to a general region but not well developed in that region. In such cases it is an important part of the work of this section of the office to develop this enterprise. (See "Types of Farming in the United States," Yearbook U. S. Dept. of Agriculture for 1908.)

In doing this, great circumspection must be used. In the first place, it must be certain that the enterprise is well adapted to local conditions. Another very important point which must be considered is the probable effect upon the markets of a large increase in any enterprise. As was stated earlier in this bulletin, those enterprises which represent the principal crops and types of live-stock farming of the country may usually be largely increased in a given limited territory without disturbing the supply and demand to any noticeable degree; but enterprises which are themselves only a small part of the agriculture of the country, such as beans, hops, and even potatoes, which so far as soil and climatic conditions are

concerned are enormously less developed than they might be in this country, should not be encouraged to such an extent as to threaten great overproduction. In regions that are more or less segregated from the general markets this applies even to enterprises that are largely developed in the country as a whole. In such regions the district leaders especially should make it a part of their duty to determine what the possibilities are in the way of marketing a largely increased product of any kind before the effort is made to increase production to any considerable extent. District leaders should read carefully what is said on pages 9 to 14 on this subject.

In determining the enterprises that are to be encouraged in a given region careful attention should be paid to the relation of crops to soil types. Supervisors and county agents especially should give attention to this matter. Very frequently it will be found that one variety, say, of corn is adapted to rich bottom land while another variety in the same general region is adapted to the thinner uplands. In general, attention should be given to the character of the local varieties that are grown and the relation of these varieties to the various types of soil occurring in the region.

In many parts of the country efforts are being made to introduce new crops. For instance, alfalfa is being tried by farmers all over the country. Soy beans are also under experiment very generally on farms in the eastern part of the United States. In recommending any new crop to the farmer the soil requirements of this crop should be thoroughly understood, as well as the effect it will have upon the seasonal distribution of labor on the farm. Both soy beans and cowpeas have had some difficulty in finding a place on farms in the eastern United States because of the fact that they require a good deal of labor at the same time as corn, and hence interfere to some extent with the seasonal distribution of labor. All these questions should be taken into account in recommending any new enterprise to the farmer.

The relation of the amount of power employed per individual to profit in farming has been quite fully discussed in the comparison of one-man cotton farming with one-man wheat farming. (See pp. 17–23.) In the first of these types of farming the man utilizes only one work animal, and this one not to its full capacity. In the other, one man usually uses five horses and keeps them busy during nearly the whole season for field work. By referring to the data given on page 20 it is seen that the average labor income on the cotton farm where the farmer owns his land is about $260 a year, while on the wheat farm it is about $1,560. These two types of farming also illustrate the relation between the amount of capital employed and the profit. The cotton farmer employs very little capital, and his capital income is less than $100. This, of course, will vary with conditions.

On the other hand, the capital income of the wheat farmer is over $1,000 per year.

One of the important problems under investigation in this section of the office is the number of horses which it is practicable for one man to use in all kinds of farm operations in all sections of the country. District leaders are instructed to give particular attention to this problem, but county agents and supervisors should also make observations on this point whenever the opportunity offers. In the wheat-growing sections of the State of Washington one man utilizes the power of from four to six horses in nearly all kinds of field operations. Is a similar practice feasible in other sections? A recent farm-management survey in the State of Illinois developed the fact that teams of four and five horses are common in that section, and the labor income of the farmers there is more than twice as great as it is in other regions where smaller teams are used.

In this connection particular attention should be given to the possibility of uniformity in the size of equipment from the standpoint of the number of horses employed. Thus, if a farm is large enough to justify employing four horses, would it be advisable to have practically all of the work on the farm done by four-horse teams and thus save the time of one man?

The place of mechanical power on the farm is being investigated in connection with the farm-equipment studies already outlined. (See p. 51.) Bulletin 170 of the Bureau of Plant Industry, entitled "Traction Plowing," deals with this subject.

The relation of profitableness in farming to the amount of capital employed, to the distribution of this capital between land, buildings, and other factors of production, and to the number of laborers employed are subjects that are studied largely in connection with farm-management surveys and farm-equipment investigations, which are conducted in another section of the office. (See under "Farm economics," pp. 40–53.) The results of such studies are utilized to the fullest extent in connection with demonstration work, which relates as much to the redirection and reorganization of agriculture as it does to the conduct of farm work.

In regions where farming is not generally profitable because the holdings are too small for the types of farming adapted to local conditions, farmers should be encouraged to increase the size of their holdings either by purchase or by leasing. It is also a part of the duty of those engaged in demonstration work to give information to farmers concerning the amount it is wise to invest in dwellings and other farm buildings, the number of work horses that could be profitably used, and the character and quantity of machinery and other equipment justifiable under any given conditions. In this connection the information given in bulletins issued by the Section of

Farm Economics of this office is of value. (See Bulletin 212, Bureau of Plant Industry, entitled "A Study of Farm Equipment in Ohio," and Circular 44, entitled " Minor Articles of Farm Equipment.")

The seasonal distribution of labor on the farm and the maximum utilization of minimum equipment which good seasonal distribution of labor renders possible is a subject to which representatives of this section of the office should give attention. (See pp. 14–24; also see the article entitled " Seasonal Distribution of Labor on the Farm," Yearbook U. S. Dept. of Agriculture for 1911.)

In most parts of the country on farms devoted to the ordinary field crops the working season may be roughly divided into the following periods:

(1) Spring: Preparing land and seeding spring crops.

(2) Late spring and early summer: Cultivation of intertilled crops.

(3) Midsummer: Hay and grain harvest.

(4) Late summer and early fall: Preparing land and seeding winter crops.

(5) Fall: Harvesting fall-maturing crops (corn, potatoes, cotton).

(6) Winter: Care of stock, repairing equipment, laying in fuel supplies, cutting timber. mending fences. etc.

Plowing for spring crops may occur during any of the periods 1, 4, 5, or 6.

To have the labor evenly distributed between these various periods increases the proportion of the time during which the farmer is profitably employed and reduces the amount of power and equipment required to farm a given area. It is only in exceptional cases that such even distribution of labor is not important (p. 17). On most farms it is highly desirable, and occasionally a farm will be found on which the seasonal distribution of labor is the critical problem. As stated previously in these pages, most systems of farming which have become general in a region are at least rough approximations to systems that are ideal in this respect. The problem then is usually not that of completely revolutionizing the system which prevails on a farm but rather that of making slight adjustments of the system to render it more satisfactory from the standpoint of labor distribution. Frequently a slight increase in the area of fall-sown crops will relieve the congestion of work in the spring and reduce considerably the number of work animals required on the farm. Sometimes a change in the order of the crops in a rotation will obviate the necessity of plowing some fields, for some crops leave the land in condition for certain others without plowing. Occasionally a farm will be found whose owner has attempted to break away from the current practice in the matter of crop rotation and has established a system that gives exceedingly poor distribution of labor. Such farmers usually see the error of their way after a few years, but they frequently lose not a little money before they realize

what is wrong with the systems they have adopted. Farms of this character may need radical changes in the cropping system in vogue in order to secure a satisfactory distribution of labor throughout the season.

It is desirable that representatives of this section of the office should work out in detail a few systems of cropping, based on the crops commonly grown or that should be commonly grown in their territory, each theoretically perfect from the standpoint of the seasonal distribution of labor. The knowledge gained in working out these systems will well repay the effort required. Such work gives an insight into some of the important problems that arise in the management of the farm. It impresses on the mind what crops compete with each other for labor at the same season of the year and those that do not compete. The working out of a few such systems will enable the student of farm organization to see quickly defects of farm organization when these defects relate to seasonable distribution of labor, which they frequently do. It will also fix firmly in mind the different problems of organization on farms of different size. If the farm happens to be of just the proper size to give adequate employment to one man and two horses when the land is devoted to the ordinary field crops, the problem of its organization is very simple indeed. Attention has already been called to the fact that farms of this size are not only more common in the States of the Middle West than those of other sizes, but that farms of this size are increasing in numbers, while those that are somewhat less in area are decreasing in numbers in those States. On the other hand, in the older States, especially near the great market centers, these smaller farms are increasing in numbers, because there the problem of their proper organization has been worked out. One can hardly appreciate the full meaning of these facts without attempting to work out systems of farming for farms of different sizes with a view to obtaining on farms of various sizes adequate employment for the farmer and the capital, labor, and equipment that might be used to advantage on a given farm.

The attempt to work out cropping systems that give good distribution of labor also reveals the fact that the system of management adopted with a given crop is frequently governed to a large extent by the exigencies of farm operation. Thus, whether the land for a given corn crop shall be plowed in the fall or the spring is determined in practice more generally by the amount of work the system in vogue calls for at each of these two seasons than it is by any theoretical advantage in the matter of yield that would come from plowing at either of these two seasons.

In regions where systems of farming prevail that bring only a meager income to the farmer or are otherwise seriously faulty, as

is the case with the single-crop cotton system of the South, it is necessary to work out systems which differ materially from those commonly found. In the cotton States, for instance, if single-crop cotton growing is best under the circumstances, the problem then is not one of farm organization but is that of securing the highest possible yield, and the principal problem to be solved is that of supplying abundant humus to the soil. But if land is abundant and labor scarce, and especially on farms where the owner and his family do the major portion of the field work, in order to increase the family income materially it is desirable to work out a system of farming that will permit the use of at least 2-horse teams in plowing cotton lands and in cultivating the crop, and then provide other crops which will fully occupy the time of the available labor and horse power when not required by the cotton crop.

The usual rotation recommended for the cotton region is cotton followed by corn, and that followed by winter oats, after which cowpeas are sown as a summer hay crop. But this rotation does not give an entirely satisfactory distribution of labor. If we add to it a fourth year of winter oats and summer cowpeas, or if we substitute for the cowpeas Japan clover (lespedeza) and leave it down two years, we increase the area one man can farm and secure a better distribution of labor during the year.

In order to be able to understand the effect a given enterprise has upon labor distribution it is necessary to be familiar with the details of the management of that enterprise. It is therefore an important part of the work of representatives of this section of the office to familiarize themselves with these details. The following information concerning every kind of farm enterprise should be secured:

(1) The kind and number of operations required by the enterprise.
(2) The dates these operations may or should occur.
(3) The crews (men, horses, and machinery) used in these operations.
(4) The amount of work each of these crews performs in a day.
(5) The percentage of time available for each operation at the season in which it is performed.

These details of enterprise management are highly variable. For instance, the kind and number of operations in growing the cotton crop are different on different farms in the same community and are widely different in different sections of the country. The same is true of practically every other farm enterprise. It is therefore necessary to study these questions broadly and to become familiar with the permissible variations in methods. Some of the problems involved in this study are complex and difficult. This is especially true of the crews used, the amount of work done in a day, and of the per-

centage of time available at different times of the year, especially for field work.

Every representative of this section of the office should study extensively the subject of standards of farm labor. They should read carefully what is said on this subject on pages 14 and 15.

An easy method of determining the percentage of time available for field work during any period of the year is as follows: Suppose it is known that during the months of August and September in a given locality one man with two horses can, on an average, plow, harrow three times, and drill 40 acres of wheat. The percentage of available time may then be found thus:

*Time required for 1 acre in various farm operations.*

| Operation. | Day's work. | Time for 1 acre. |
|---|---|---|
| | *Acres.* | *Part of day.* |
| Plowing | 1.75 | 0.571 |
| Harrowing (3 times) | 10 | .300 |
| Drilling | 8 | .125 |
| Total | | .996 |

It would require $40 \times 0.996 = 39.8$ actual days of work to put in this crop. Since there are 61 days in August and September, the available time is $39.8 \div 61 = 0.653$, or 65.3 per cent—practically 2 days in 3 on an average. The available time at any other season may be found in a similar manner if the area that one man can manage during that season is known. The amount of work he can do in a day must also be known.

In examining the system of management on a farm with a view to determining its weak points it is helpful to tabulate, at least roughly, the labor required by the various enterprises during each of the principal work periods. Where the organization of the farm from the standpoint of the distribution of the labor is faulty this gives an important insight into the nature of some of the problems that confront the farmer. Then, if the field man is familiar with the details of management, especially the labor distribution, of a large number of farm enterprises, it is easy to suggest changes in the system of management which will reduce the amount of work at one period and increase it at another, and this will not only decrease the amount of horse power and machinery equipment needed during the busiest seasons but will give a fuller utilization of horse power and equipment throughout the year. Where a definite system of cropping is in vogue on a farm a well-worked-out labor schedule covering the whole year will be of great assistance to the farmer, and in many cases it is worth while to work out such schedules for individual farmers. They are useful in the management of labor and are

always of value as a means of foreseeing what equipment should be made ready for work in the near future.

Most of the work of agricultural scientists has related hitherto to methods of conducting farm enterprises, and has had little to do with problems relating to farm organization or to the problems that arise in the conduct of the business of the farm. While methods of growing crops and managing live stock are only one of the factors of profitableness in farming they are an important factor. Hence, it is of the greatest importance for those engaged in farm-management field studies and demonstration work to study carefully the methods used by successful farmers everywhere. They should also familiarize themselves with the results of scientific investigations relating to the best methods of conducting all kinds of crop and live-stock enterprises. The methods used by farmers who make a satisfactory profit in farming may usually be safely copied by others unless better methods are known.

An excellent type of work, especially for the supervisors, who have charge of groups of counties, and for district leaders, who have charge of the work in a few States, is to select regions covering a few counties in which the agriculture is fairly uniform, or, if sufficiently uniform, the region may cover a larger area, and to make a detailed study of the agriculture of the region along the lines indicated in the following publications of the United States Department of Agriculture: Farmers' Bulletin 294, entitled "Farm Practice in the Columbia Basin Uplands"; Farmers' Bulletin 472, "Systems of Farming in Central New Jersey"; and Bulletin 215 of the Bureau of Plant Industry, "Agriculture in the Central Part of the Semiarid Portion of the Great Plains."

In such studies particular attention should be given to the prevailing types of farming and the reasons why they prevail, including a discussion of the general adaptability of these types of farming to local conditions. The study should include the cropping systems used, the methods employed in managing the various crops and types of live stock, the methods of soil management and the resulting yields obtained, the sizes of farms, and the general financial condition of the farmer. This work is similar to the farm-management survey work already described, but it gives more attention to the methods used on the farms and covers a much wider territory. Such a study should also include, as far as possible, the history of the changes in the local agriculture, with the causes underlying these changes. Such studies give the field man an excellent knowledge of the agriculture of the region, and when published are exceedingly valuable not only to farmers in general, but also to those seeking locations in which to purchase farms.

Representatives of this section of the office should note, whenever opportunity permits, all cases of by-industries which are not usually found on farms, such as broom making, sirup making, etc., that are used to fill in the gaps in the labor schedule. In connection with such industries an account should be obtained of the equipment and its cost, the season of the year when it demands labor or occupies labor otherwise engaged on the farm, the profit obtained from it, etc.

All representatives of this section of the office are instructed to make a record of all crop rotations found in practice, together with the farmer's reasons for following each rotation, or rather the reason for each of the crops in the rotation and the particular order in which the crops come. Study of this kind over a large area will soon show what is practicable and what is impracticable in the way of crop rotation in that region, especially if it is one in which crop rotation is quite generally practiced.

Similar records should be made of all cropping systems for specific purposes that are found. Thus, in some of the tobacco-growing regions, a rotation is used in order to increase the yield of tobacco. The character of such rotation should be recorded and reported to the office. On stock farms frequently the rotation is planned to meet the needs of the stock on the farm. Such rotations should be studied carefully. In studying any rotation attention should be given to the labor distribution it requires. It is also a part of the work of the representatives of this section of the office to plan cropping systems, either of a general nature or for specific purposes, for such farmers as may desire them.

Another subject for investigation by the representatives of this section of the office is the cost and practicability of different methods of performing the same work. For example, corn may be cut and shocked by hand; by means of a 2-row, 1-horse platform cutter run by two men, with or without an extra man to make the "horses" for the shocks and pick up scattered stalks and ears; or by means of a corn binder with or without a shocker attachment. Wheat may be bound, shocked, and thrashed; bound, shocked, stacked, and thrashed; headed, stacked, and thrashed; or it may be harvested by a combined header and thrasher. Manure may be distributed by hand from a wagon, or it may be distributed by means of a manure spreader. There are many other farm operations that may be similarly performed in a number of ways. The problem is to find the cost of performing the operation in each of these ways and to determine which is most profitable and most practicable under given conditions.

Another problem closely related to the foregoing is that of crew work, which is also studied in the Section of Farm Economics. It is important to study all kinds of farm operations that require a number of men, teams, and implements. For instance, in putting silage in

the silo a study should be made of the number of men, teams, and implements, the work each does, and the relative time of beginning the work on the part of each member of the crew. Harvesting and stacking hay and harvesting, stacking, and thrashing wheat are all examples of crew work which should receive attention. District leaders and supervisors of groups of counties will have opportunity to make studies of this kind.

The relation of methods of marketing to profit in farming is a subject of special study in the Section of Farm Economics, but those engaged in farm-management field studies and in demonstration work are instructed to give the subject such attention as conditions permit. This matter is further discussed in connection with the details of the extension work.

There is probably no more profitable work in which representatives of this office are engaged than the improvement of old, well-established systems of farming. It is seldom that any system of farming is so well perfected on even a single farm that a few simple changes will not greatly increase the net profits. It may be a slight change in the rotation, the elimination of boarder cows, the use of lime to correct soil acidity, or some other slight change that can easily be suggested by one who has visited hundreds of successful farms which will change failure to success, not only on one farm but sometimes over large areas.

In the dairy districts of the Central West a large part of the gross income on many farms goes toward the purchase of brewers' grains, bran, and other concentrates. The successful production of alfalfa cuts out this great expense. Alfalfa, however, is often a failure without lime and inoculation, and is much improved by the addition of organic matter to the soil and by comparatively deep plowing. These farmers realize the need and the value of alfalfa, but few of them know how to grow it successfully. As soon as they learn how to get large yields of alfalfa their entire system of farming will become highly profitable at once. As simple a thing as soil inoculation has often greatly increased the yields of alfalfa and made dairying highly successful over large areas.

On sandy lands in the North the introduction of hairy vetch as a green-manure crop and as a seed crop has greatly increased the fertility of the soil and has added much to the net income from farms in these districts. The growing of mammoth, or zigzag, clover for seed on such soil was found to be profitable on a few of these farms and through the influence of our field men it is now grown profitably over large areas of the sandy districts.

Skillful and well-informed farmers who have not yet attained the financial success that will warrant heavy investment in pure-bred live stock and yet who are desirous of producing such stock have been

placed in a position to get the required capital without the necessity of borrowing. This has been brought about by some of the field men by a very simple combination of the skill of the farmer and the money of the capitalist, and in every case in which this has been done the results have been satisfactory to both parties to the contract. The money is usually furnished by some one who is much interested in live stock, but who is so tied up with other business that he can not give enough attention to farming to look after the details of the work. As an illustration of how this works out in actual practice, an instance may be cited in the State of Wisconsin in which a few pure-bred Holstein cattle were purchased by one man and placed on the farm of another. The contract, which is to run for five years, requires that the farmer furnish all the feed, in return for which he is allowed all the milk. The farmer also receives one-half the proceeds from the sale of male calves, and no heifer calves are to be sold except by mutual consent until the maturity of the contract. At the time of settlement the original investment is returned to the investor. Of the increase the farmer receives one-third and the man who purchased the cattle receives two-thirds. This particular investment has proved highly profitable to all concerned.

This is a much more legitimate use of capital than the buying up of large tracts of arable land and holding them for a rise in value; in fact, the purchase of land for this purpose is not for the best interests of the country, while the investment of capital in all kinds of productive agriculture is to be commended.

A fertile 500-acre farm in central Michigan had been so badly managed that for 10 years it had not paid any interest on the investment and had scarcely furnished enough income to cover the running expenses. At the request of the owners, representatives of the Office of Farm Management visited this farm and studied the details of its management. On their recommendation, 4-horse machinery was substituted for 2-horse machinery, the poorest of the cows were sold and the money invested in good cows, a silo was built, and many other minor changes were made. It was also recommended that in addition to his salary the foreman be allowed 10 per cent of the net income after the expenses, not including interest, were paid. The owners objected to this at first, until they understood that for every dollar the foreman received in this way the owners would receive $9. They were then anxious to make this agreement. The first year after these changes went into effect the farm paid all expenses and 5 per cent interest on the investment of $60,000.

Not infrequently dairy farmers are found who are making no profit because their cows are not capable of producing enough. By inducing them to keep records of the product of each cow and then

to dispose of those that fall below the standard unprofitable farms may frequently be made profitable.

In many sections of the country the systems of farming do not provide a sufficient supply of humus in the soil. For instance, in many localities in the Ozark region the leading crops are corn and wheat, and very little else is grown on many farms. It has been found that a rotation of corn, corn, cowpeas, wheat, wheat is well adapted to that region, and by sowing cowpeas in the first-year corn, wheat in the second-year corn for winter pasture, and cowpeas as a catch crop after the second-year wheat an excellent cropping system is obtained that not only keeps the soil well supplied with humus and distributes the work so as to employ the same number of teams at all times during the season for field work, but furnishes roughage that renders the system well adapted to almost any kind of live-stock farming. While this system is a marked improvement over those prevailing quite generally in this region, it introduces only one crop that is new to the farmers, and thus does not appear to them as a radical change from their present methods. It also builds up the soil rapidly. Many other illustrations might be given showing that apparently simple changes in the systems of farming found on many farms and frequently over entire regions will often suffice to convert poor systems into good ones.

The work thus far outlined for this section of the office relates to what may be called farm-management problems proper. There are many agronomic problems which are best studied in their relation to farm practice. This is especially true of those problems that are so broad that ordinary experimental methods will not solve them. Perhaps the most important general problem of this character is the relation of farm practice to crop yield, already mentioned in discussing special farm-management problems.

This is a problem in applied agronomy. Every farm that has a system of soil management which has been in vogue long enough to show its effect on crop yields has a lesson to teach regarding the relation of various practices to soil fertility. There are many farms of this kind. The aim of this work is to secure from each of these farms a record of every detail that affects crop yields, such as the varieties of crops grown, the character of seed used, the depth of plowing, methods of preparing seed bed, methods of intertillage, including the kinds of implements used, methods of managing and applying manure, the kind and quantity of manure used, and complete statements of the methods relating to the use of fertilizers, lime, etc. A record should also be made of the character of the soil and of the crop yields obtained. Large numbers of such records of farms distributed over wide areas will, it is believed, permit of such statistical

treatment as will reveal the influence on crop yield of each of the factors mentioned. Comparatively little progress has been made on this problem by the experimental method, when it is remembered that it has probably received more attention than any other agronomic problem. The main reasons for this are our lack of knowledge of conditions existing within the soil, the great variability of the experimental results, and the limited application of results obtained in a given locality. The two latter difficulties can be overcome only by securing large masses of data from all the numerous soil types, such as it is possible to secure by a far-reaching study of farm practice. This is another type of work in which, on account of the great variability of experimental results, no great additional accuracy can be obtained by a highly accurate determination of yields. In such cases quantity of data is vastly more important than accuracy of single observations.

Before the full value of the method of farm-practice investigation was realized the problem of the relation of different types of farming to crop yields had been attacked by the experimental method in cooperation with the Kentucky and the Maryland agricultural experiment stations. At each of these stations extensive series of plat experiments were instituted, in devising which an attempt was made to provide a test of certain types of farming which would represent in a general way all types. In order to secure definite results it will be necessary to continue these experiments during a long series of years. In time they will form a useful check on the results obtained in the study of farm practice, even if the results are applicable only to the soil types on which the experiments are conducted.

Some features of the relation of farm practice to crop yield may very well be studied independently. One of these is the management of manure. Much study has been given to the chemical composition of manures and to the effect of different methods of handling manure on the loss of chemical ingredients. Yet farm methods are little better now than they were two or three generations ago. This is partly because the problem of manure management is a difficult one in practice, and farmers have been left to their own resources in solving it. The task has been too great for the average farmer. The object of the present study is to help the farmer in the solution of the problem of securing the benefits of the manures with the least expenditure of time, effort, and money. It involves a study of the equipment for saving manure and protecting it from the weather; the cost, adaptability, and care of this equipment; the point in the rotation at which manure is applied and the quantities used; the equipment for distributing manure, the cost and practicability of this equipment, the power required to

operate it, and the labor cost of distributing manure by means of it; the quantity of available manure produced per head of stock of different kinds under different systems of stock management; the relative value of manure from different kinds of animals and of the same kind under different systems of feeding; the kinds of crops to which manure from different animals is best adapted; the methods of composting; the conditions which justify the expense of composting; the cost of manure when it is obtained from outside sources; the value of manure as measured in increased yields under different conditions, etc.

A related problem which may be studied independently and on which a bulletin has already been issued by this office is farm practice in the use of commercial fertilizers. (See Farmers' Bulletin 398, entitled "Farm Practice in the Use of Commercial Fertilizers in the South Atlantic States.") It involves a study on individual farms of the kinds of fertilizers used, with reference both to the fertilizing substances and to the percentage of fertilizer elements contained; sources from which the fertilizer is obtained; methods of mixing; proportion of various ingredients required to give mixtures of any desired composition; use of ready-mixed compared with home-mixed fertilizers; equipment required for storing, mixing, and distributing; cost and practicability of such equipment; cost, including labor and time required for mixing and for distributing; rate of application; crops to which applied; time of application; manner of application, whether broadcast on surface, in rows with the seed, in rows and mixed, or covered with soil before planting the seed; means used in keeping up the humus supply so as to make fertilizers more effective; relation to yields; cost of fertilizer; accumulative effects on soil and how to overcome injurious effects, etc.

Local agents in regions where commercial fertilizers are largely used, especially where they are used in large quantities, should ascertain what saving can be made by the farmers in buying fertilizer ingredients separately and mixing them themselves. If the saving is found to justify encouraging this practice it is well to give demonstrations in the home mixing of fertilizers.

Farm practice in the use of agricultural lime may also be studied as an independent problem. District leaders, State leaders, supervisors, and local agents should cooperate in ascertaining the sources from which agricultural lime may be obtained and the prices at which the lime can be delivered at local stations. Both local agents and supervisors should give careful study to the needs of the various soil types in their territory concerning lime and to the best practice in the use of this soil amendment. Important service can be rendered to farmers by helping them to secure a good quality of lime at the least possible expense.

Another special problem, which is a part of the general problem of the relation of farm practice to crop yields, is the use of green manures as a means of putting humus into the soil. A study should be made of the crops adapted to this purpose and the places they may best occupy in the cropping system, as well as the effect produced by the use of such crops.

### WORK OF THE LOCAL AGENTS.

It is impossible to outline in detail the problems the extension worker will meet with in any given locality in advance of the actual investigation in the locality, because these problems are so numerous and vary so greatly with local conditions. The extension worker himself must investigate local conditions and determine the particular needs of the community in which he works. The suggestions which follow, therefore, are not presented with the idea that they cover the ground fully in any given case, or with the expectation that local agents will undertake any large number of the problems to which attention is called. The best results will usually be obtained by concentrating very largely on one or two, or at least a few, lines of extension work, giving only incidental attention to others. From year to year the lines on which effort is concentrated will change according to the exigencies of the case.

Before undertaking extension work in any locality it is an excellent plan for the extension worker to tabulate all available census data concerning the agriculture of the region. He should also construct a rainfall map from the available data of the United States Weather Bureau and in all western sections should familiarize himself with the seasonal distribution of the rainfall, as this is important nearly everywhere in the West. He should determine the length of the growing season and should become familiar with the geology of the region, and if the Geological Survey has made a topographic map he should secure a copy. If the Bureau of Soils has made soil surveys, copies of the soil maps should be obtained and studied with care. Study of this kind makes a man familiar with the region in a general way even before he visits it and puts him in a position to assimilate data gathered by the study of farm practice much more readily than if he did not have this general knowledge of the locality.

The extension worker should also familiarize himself with the organization of the cooperating State institution and of the United States Department of Agriculture in order that he may know the sources of information in these institutions and become familiar with the work of experts who can render service to farmers in his territory. He should especially become familiar with the literature of these institutions relating to the region in which he works.

In beginning extension work in any locality one of the first things to do is to hunt up all the successful farmers who can be found and to make a careful study of their work. This should include a study of the types of farming followed, the cropping systems used, methods of keeping up soil fertility, and the details of the management of each enterprise on the farm. For suggestions as to the manner of making such study, see what is said under the heading "Study of successful farms," on page 37 of this bulletin.

A striking advantage which arises from this study of successful farms is the fact that the field man soon acquires a vast amount of local knowledge which makes him a welcome visitor on any farm, for farmers are always eager to learn the methods of those whom they regard as successful. They will listen eagerly to a description of an actual farm or any of its methods, while they will look askance at any suggestion that has not been tried out in practice. Farmers' Bulletins describing in detail the system of management on a single farm are read eagerly, and bulletins of this kind have had a larger circulation than any other type of bulletin prepared in the Office of Farm Management. Farmers practically never undertake to follow in detail the systems outlined in these bulletins, but they do adopt certain practices from them that are adapted to their conditions. (See Farmers' Bulletins as follows: 242, An Example of Model Farming; 272, A Successful Hog and Seed-Corn Farm; 280, A Profitable Tenant Dairy Farm; 310, A Successful Alabama Diversification Farm; 312, A Successful Southern Hay Farm; 326, Building up a Run-Down Cotton Plantation; 355, A Successful Poultry and Dairy Farm; 364, A Profitable Cotton Farm; 432, How a City Family Managed a Farm; 437, A System of Tenant Farming and Its Results; 454, A Successful New York Farm. See also Bulletin 102, Part II, Bureau of Plant Industry, entitled "A Successful Dairy Farm.")

In studying the details of the management of individual farms it is well to give attention to the relation of the farmer to his hired labor. This involves a study of housing and boarding; laborers' privileges, such as the use of a horse and buggy on Sundays and holidays, the use of a garden, the keeping of cows, pigs, and chickens, and access to farm papers and other available literature; the personal relations of the farmer and his hired labor; permanency of employment; and the relation of all these factors to the difficulty of securing farm laborers and the efficiency of this labor.

In studying the agriculture of a community attention should be given not only to defects in methods, but to defects of organization. The extension worker should read carefully the discussion of farm organization and equipment in the first part of this bulletin. (See pp. 9–30.)

Not only is it possible for the extension worker to help the farmer in the matter of the selection of enterprises that are to constitute the basis of his business and in the details of the conduct of each of these enterprises, but he can render occasional assistance by giving advice on such subjects as the cost of farm dwellings and plans and cost of other farm buildings. (See the discussion of the "Cost of farm dwellings," pp. 29–30 of this bulletin; also Farmers' Bulletin 438, entitled "Hog Houses.") He can be of special help by giving advice concerning equipment in farm machinery and in the care of this equipment. The extension worker should also familiarize himself with the number of work horses required on farms of a given size and type, as well as the number of laborers at different seasons of the year. This information can be obtained in connection with the study of the work on successful farms.

The maintenance of crop yield should always be a major consideration. The man engaged in extension work should master this subject locally as well as generally, and wherever yields are less than they should be an effort should be made to correct this defect.

It is important that farmers should use good seeds. So far as practicable farmers should be encouraged to grow their own seeds and should be taught how to select and care for seeds for the next year's planting. Where it is not practicable for farmers to do this, it is well to encourage a few men in each locality to produce a high quality of seeds to be sold locally. But this should not be overdone, as there might not always be a market for the seeds. Where it is not practicable to have seeds grown locally, service should be rendered to the farmer by helping to secure good seeds from other localities.

It must not be forgotten that of the 6,000,000 farmers in this country many of them possess great ingenuity and originality, and in practical affairs these men frequently work out the solution of problems that are of general interest. Extended study of farm practice in any region will reveal many interesting things of this character.

The Office of Farm Management has issued a number of important bulletins relating to methods of exterminating some of the worst weeds of the country. (See Farmers' Bulletins: 279, A Method of Eradicating Johnson Grass; 368, The Eradication of Bindweed or Wild Morning-Glory; 464, The Eradication of Quack-Grass; and Circular (Document 416), Bureau of Plant Industry, entitled "The Wild Onion.") Local agents should familiarize themselves with such of these bulletins as are of local interest. Where there is a serious weed pest the methods for the control of which are known, the farmer should be taught this method. Where noxious weeds are found for which no method of control is known, the State experiment station

and the Office of Farm Management should be notified. It is, in fact, an important part of the work of the local extension man to put farmers in touch with the work of the various experts of the Department of Agriculture and the cooperating State institution.

Particular attention should be given to the methods of preparing land for seeding, including the season of the year at which plowing is done, the depth of plowing, the methods of fining the seed bed, etc. The methods and the implements used in tilling intertilled crops should be studied carefully. Usually the practice of the most successful farmers should be the guide in local practice unless it is known that there are better methods. The possibility of using plows, harrows, and tillage implements of large size should receive attention. On farms that are large enough to justify the practice, and in regions where conditions permit, it is economy to use the largest practicable sizes of all field implements.

In the matter of insect pests and fungous diseases local agents are not expected to become experts. Generally speaking, the best they can do is to call to the attention of experts in the State experiment station and in the Department of Agriculture problems of this character when they arise locally. In many cases either the State experiment station or the proper office in the Department of Agriculture will be able to furnish directions which the local agent can apply or even which the farmers can apply under the direction of the local agent. This ought to be possible in the treatment of grain for smut and in the spraying of orchards. Frequently, also, the method of controlling insect pests can be handled in a similar manner.

In regions where there are orchards improperly cared for, the local agent should familiarize himself with orchard practice and give demonstrations in pruning and spraying, and also in picking, sorting, and packing fruit for the market. Some of the local agents have been very successful in this work and have greatly increased the income of farmers from the sale of fruit from orchards which before had brought the farmer little or nothing.

In any locality where some special crop, such as potatoes, tomatoes, apples, etc., is important, the local agent and the supervisors should make themselves familiar with the management of these enterprises in order to be able to teach farmers the most improved methods. (See Farmers' Bulletins 323, entitled "Clover Farming on the Sandy Jack-Pine Lands of the North"; 365, "Farm Management in Northern Potato-Growing Sections"; 491, "The Profitable Management of the Small Apple Orchard on the General Farm. See also Bulletin 124, Bureau of Plant Industry, "The Prickly Pear as a Farm Crop"; Circular 28, Bureau of Plant Industry, "Clover-Seed Production in the Willamette Valley, Oregon"; and Farmers' Bulletins

relating to particular crops; also similar State experiment station bulletins.)

The marketing of the products of these special crops is usually one of the most serious problems that confront the farmer, and all assistance possible should be given in this matter. Particular attention should be paid to the size and the style of package which the market demands. Farmers should be made to understand that attractiveness is worth even more than intrinsic quality in the sale of farm products, especially those that are exposed for sale in retail stores in the form in which they leave the farm.

Many farmers will be found who are making the attempt to keep some kind of record of their financial transactions and the work on their farms. Such farmers should be put in touch with the work of the Section of Farm Economics of this office, where much attention has been paid this subject; also with such cooperating State institutions as are doing work along this line.

In most localities it will be found desirable to hold meetings at country schoolhouses or elsewhere for the discussion of timely subjects. At the proper season these meetings may be devoted to the discussion of such subjects as lime, its source, cost, where and when to apply; fertilizers, kinds to buy, quantities to use, how and to what crops to apply, prices, how to mix, etc.; potato culture; renovation of orchards; the farmer's garden, etc.

In reaching the farmers, free use should be made of local papers. Copies of all articles prepared for publication in this manner should be sent to the Office of Farm Management. It is an excellent plan to secure a list of the names and addresses of all the farmers in the territory of the local agent, with brief data concerning their farming. The possession of these names permits the preparation and distribution of timely circulars, which should in all cases be previously approved by those in general charge of the extension work, including the section leader in this office.

Local agents can be of much assistance to farmers by helping them to organize associations for such purposes as the cooperative marketing of fruits and truck crops, the purchasing of fertilizers and seeds, etc. It is not wise for local agents to accept official positions in such organizations, since they should be managed by the farmers themselves. The idea is to teach the farmers to help themselves. In many sections of the country local agents have organized farm-management clubs and guided them in the consideration of real farm-management problems.

All those who are engaged in agricultural extension work should keep in close touch with the rural schools and should attempt to interest both teachers and pupils in the boys' and girls' agricultural club work. Much service can also be rendered in the introduction of

agriculture into the rural schools by giving advice to teachers concerning the nature of the work that can be done, and especially by putting them in touch with sources of information in the State colleges and in the Department of Agriculture.

### BOYS' AND GIRLS' AGRICULTURAL CLUB WORK.

The Office of Farm Management employs a specialist whose business it is to assist State and local authorities in the organization and conduct of boys' and girls' agricultural clubs. The boys' corn clubs and the girls' canning clubs have been very successful wherever work of this kind has been undertaken and have aroused a great deal of enthusiasm for improved methods of farming and farm-household administration. Full information regarding the details of this work and the service the office is prepared to render in connection with it will be sent to any applicant. This work in the cotton States is conducted by the Farmers' Cooperative Demonstration Work; in other States by the Office of Farm Management.

### UTILIZATION OF CACTI AND DRY-LAND PLANTS.

When the Office of Farm Management was organized and the work with grasses and forage plants transferred elsewhere the work with the cacti and dry-land plants was retained because of the personal interest of representatives of this office in certain important problems relating to these, and it has since been maintained in the Office of Farm Management at the request of those in charge of the work in order that they might be free from administrative details and thus be able to devote their entire time to the investigation.

The first investigations of the cactus as an economic plant represented a study of farm and range practice in the use of these plants as forage for cattle. This study revealed so much of interest that the data obtained in it were published and formal investigations instituted with a view of determining just what value the cactus might possess both as forage in its wild state and as a farm crop. A large collection of varieties and species was made, especially in our Southwestern States and in Mexico, but also from other parts of the world. These have now been grown for several years with a view of ascertaining their possibilities as cultivated crops. Plantations are maintained at San Antonio, Tex., Chico, Cal., and Brownsville, Tex.

The numerous spineless forms that have been investigated have proved to be very sensitive to cold and can be safely grown only in localities where the temperature does not fall below 20° F., and seldom reaches this minimum. These spineless forms make good chicken feed, are excellent succulence for the dairy, and are relished

by hogs. Some use is also being made of the plants as a succulent feed for Belgian and other hares. This group of plants can be made a paying crop where the conditions of temperature and moisture are suitable.

Much time has been spent in working out the cultural details of the cactus when grown as a farm crop, such as the distance between the rows and between plants in the row, methods of planting, the methods and amount of cultivation required, the age at which the forage may be harvested, and the methods of harvesting. One great advantage of the spiny cactus is that all that is necessary in feeding it is to burn off the spines from plants standing in the field. Stock may then be given free access to the field, where they will confine their attention entirely to plants that have been thus artificially prepared for them. This makes the harvesting of the crop, as well as the feeding of the stock, a very simple and inexpensive matter.

Several feeding experiments have been conducted to determine the forage value of the cacti. At the present time such an experiment is being conducted in cooperation with the Bureau of Animal Industry of this Department. These investigations include the conduct of digestion experiments. An effort is being made to determine the proper place of cacti in the rations of live stock of different kinds and to determine the effects of continuous feeding of cactus forage for long-continued periods. The following publications relating to cacti have been published: Bulletins of the Bureau of Plant Industry, No. 74, The Prickly Pear and Other Cacti as Food for Stock; 116, The Tuna as Food for Man; 124, The Prickly Pear as a Farm Crop; and 140, The Spineless Prickly Pears; Farmers' Bulletin 483, The Thornless Prickly Pears; and Bulletin 91 of the Bureau of Animal Industry, Feeding Prickly Pear to Stock in Texas.

The range investigations being carried on by this office are designed to secure accurate data upon the following subjects:

(1) Assurance as to the possible recovery of run-down ranges of different types under partial and complete rest, and the rates at which recovery occurs.

(2) The possibility of improving the native ranges artificially.

(3) The carrying capacity of the ranges, present, normal, and possible.

(4) An estimate of the area and geographic distribution of the open range, with a summation of published topographic and climatic data relating thereto.

(5) The chemical composition of and the botanical and economic data concerning the different species of range forage plants.

(6) Range management with different kinds of stock with and without fence.

Several years ago an area of over 50 square miles of badly overstocked and depleted open range land in southern Arizona was set aside as an experimental range and placed under the control of this office. The land was fenced and the greater part of it has been allowed to recover naturally. The remainder was divided into several

pastures and has been carrying stock, mostly cattle, all the time. Data as to the exact number of head upon known areas have been obtained for something over three years. The areas in question have been under the management of different men, each using his own judgment as to the best method of treatment, modified only in so far as necessary to secure accurate data.

Data as to the production of both spring and summer feed at various places on the large unstocked field have been collected for a number of years. For the past three years the grass crop on several areas 25 to 40 acres in extent within this large field has been cut and the quantity of hay per acre determined.

Thus far this experimental range has demonstrated that a range in southern Arizona will recover approximately its normal carrying capacity in three to five years if allowed complete rest. This fact was seriously doubted by experienced stockmen of the region before this series of experiments was commenced. It has also shown that with proper control this range will slowly improve while carrying stock almost up to the limit of its carrying capacity. Data upon this point show a slight general increase in carrying capacity of the areas under stock.

The hay-cutting operations and the collecting and weighing of the spring feed are beginning to furnish accurate data on the actual amount of feed per acre produced annually on the protected range. These data and those obtained from the records of stock actually carried on adjoining measured areas will give something definite as to the normal carrying capacity of this region.

Numerous attempts have been made upon this large area and on another area of about 2,500 acres to increase artificially the quantity of forage produced by seeding, tillage, and conservation of the rainfall and run-off. Many different kinds of forage-plant seeds have been sown and cacti of several different species have been planted in an attempt to secure increased productivity on the areas referred to, but only a nominal increase in the forage crop has been secured. The sowings of some of the native grass seed have given positive results in a few cases, but mostly such attempts have been fruitless.

Extensive attempts to retain the surface run-off by systems of low dams have given some improvements in the forage crop, but the expense was out of all due proportion to the results achieved. Results from tillage experiments have been negative in character.

On all field trips of the parties in charge of these investigations data are being collected as to the area of open range land in the arid region and its geographic distribution, in order to be able to map it roughly. Published meteorologic and topographic data which affect the natural distribution of the native forage plants are being

compiled from time to time as opportunity offers. Field notes of the distribution and density of forage plants, especially of grasses, are taken at all times.

For several years specimens of all kinds of forage plants have been collected on field trips for chemical analysis. The procedure has been to collect a sufficient quantity for the chemist and to make one or more botanical specimens of the same material, with occasional photographs showing the habit and habitat of the species. Copious field notes are taken on the economic importance of the species. The material for analysis is sent to the Bureau of Chemistry for a quantitative analysis, this work being carried on in collaboration with that bureau. A large number of such analyses have already been completed and the botanical notes relating thereto collected in a form ready for publication. More than 100 species of important grasses and grasslike plants are listed. It is expected that this investigation will result in a reference work for the chemical and botanical data available on all species of wild forage plants.

The remaining work on the utilization of dry-land plants relates largely to range management, and as this is mainly a study of range practice, this particular line of work is closely related to the general work of the Office of Farm Management. The work in range management relates to the various methods of management of stock, particularly cattle and sheep, upon the native ranges of the arid region, and considers the methods in common use on fenced and unfenced areas and the relation of the business to the forage conditions of the different sections. Data as to the cost of various operations, the construction and care of machinery and equipment, methods of handling stock, causes of loss of stock, and methods of disposing of the output are collected and summarized. The data are obtained from experienced stockmen in different parts of the country working under different range, climatic, and commercial conditions.



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# WHAT IS FARM MANAGEMENT?

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